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The purpose of this short term study has been: 1) to develop braod bases and 2) to obtain new information relevant to the needs of the Environmental Protection Agency. These data bases are required to provide information for the Clean Air Act and the Uranium Mill Tailings Radiation Control Act. This report deals specifically with farm tasks associated with the Uranium Mill Tailings Radiation Control Act. Due to the complexity and number of projects each takss has its own summary and recommendation section. However, the two parts of the report each has an executive summary which lists all the detail with respect to the interpretations of data developed in the tasks and their associated recommendations.

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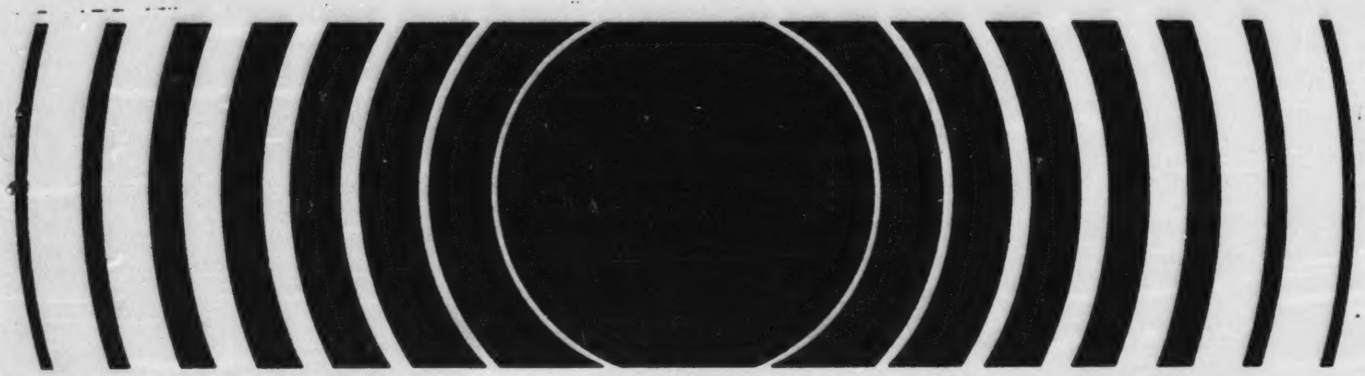

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AN ENVIRONMENTAL STUDY OF ACTIVE AND INACTIVE URANIUM MINES AND THEIR EFFLUENTS

PART II

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CONTENTS

Page

ABSTRACT xiv

EXECUTIVE SUMMARY xvi

TASK 1 - PHYSICAL AND CHEMICAL CHARACTERIZATION OF RESUSPENDED MATERIALS FROM ORE, SUBORE, AND OVERBURDEN MATERIAL 1-1

INTRODUCTION 1-1

DISCUSSION 1-1

SUMMARY 1-3

RECOMMENDATIONS 1-5

TASK 2 - RADON AND OTHER CONSTITUENTS IN MINE WATER AND EXHAUST VENTS 2-1

INTRODUCTION 2-1

EXPERIMENTAL PROTOCOL 2-1

DISCUSSION 2-2

SUMMARY 2-4

RECOMMENDATIONS 2-5

TASK 3 - THORIUM CONTENT OF OVERBURDEN, SUBORE, AND ORE 3-1

INTRODUCTION 3-1

EXPERIMENTAL PROTOCOL 3-1

DISCUSSION 3-1

SUMMARY 3-2

RECOMMENDATIONS 3-4

TASK 4 - ANALYSIS OF POLLUTANTS IN AQUEOUS EFFLUENTS AND WASTES 4-1

INTRODUCTION 4-1

EXPERIMENTAL PROTOCOL 4-1

Page

DISCUSSION 4-2

SUMMARY 4-3

RECOMMENDATIONS 4-4

TASK 5 - TRACE ELEMENTS AND RADIONUCLIDES IN SURFACE RUN-OFF FROM ORE, SUBORE, AND OVERBURDEN PILES 5-1

INTRODUCTION 5-1

EXPERIMENTAL PROTOCOL 5-1

DISCUSSION 5-4

New Mexico Abandoned Mines 5-4

Wyoming Mine 5-23

SUMMARY 5-24

RECOMMENDATIONS 5-27

TASK 6 - RADON EMISSION FROM INACTIVE UNDERGROUND URANIUM MINES 6-1

INTRODUCTION 6-1

MINE 1 6-1

EXPERIMENTAL PROTOCOL 6-1

DISCUSSION 6-2

MINE 2 6-8

EXPERIMENTAL PROTOCOL 6-8

DISCUSSION 6-9

SUMMARY 6-14

RECOMMENDATIONS 6-14

TASK 7 - RADON EXHALATION FROM ORE, SUBORE, AND OVERBURDEN FROM AN INACTIVE URANIUM MINE 7-1

INTRODUCTION 7-1

Page

EXPERIMENTAL PROTOCOL 7-1
DISCUSSION 7-1
Wyoming Mines 7-1
New Mexico Mines 7-2
SUMMARY 7-13
RECOMMENDATIONS 7-13
TASK 8 - SITE MAPPING 8-1
INTRODUCTION 8-1
DISCUSSION 8-1
New Mexico 8-1
Barbara J Mine 8-1
Poison Canyon 8-4
Poison Canyon Area #1 8-4
Poison Canyon Area #2 8-7
San Mateo Mine 8-7
Mesa Top Area 8-9
Wyoming 8-12
Morton Ranch Mine 8-12
Colorado 8-16
Uravan and Boulder Areas 8-16
Uravan Area 8-20
Mine 1 8-20
Mine 2 8-20
Mine 3 8-20

Page

Mine 4 8-20
Mine 5 8-25
Mine 6 8-25
Boulder Area 8-25
Mine 7 8-25
Mine 8 8-25
Mine 9 8-25
Mine 10 8-31
SUMMARY 8-31
RECOMMENDATIONS 8-31
TASK 9 - GAMMA MAPPING 9-1
INTRODUCTION 9-1
DISCUSSION 9-1
MORTON RANCH 9-1
SAN MATEO RANCH. 9-8
MESA TOP MINE. 9-13
POISON CANYON #1 MINE. 9-13
POISON CANYON #2 MINE. 9-16
BARBARA J MINE 9-16
EPA COLORADO WALK THROUGH. 9-16
Uravan Area 9-19
Mine 1 9-19
Mine 2 9-19
Mine 3 9-19
Mine 4 9-19

Page

Mine 5 9-19

Mine 6 9-25

Boulder Area 9-25

Mine 7 9-25

Mine 8 9-25

Mine 9 9-25

Mine 10 9-25

SUMMARY 9-31

RECOMMENDATIONS 9-32

TASK 10 - SOIL SAMPLING 10-1

INTRODUCTION 10-1

EXPERIMENTAL PROTOCOL 10-1

DISCUSSION 10-2

SUMMARY 10-21

RECOMMENDATIONS 10-22

TASK 11 - CHEMICAL CONSTITUENTS OF MILL TAILING LEACHATES. 11-1

INTRODUCTION 11-1

EXPERIMENTAL PROTOCOL 11-1

DISCUSSION 11-1

SUMMARY 11-2

RECOMMENDATIONS 11-3

TASK 12 - CHEMICAL AND RADIOCHEMICAL COMPOSITION OF AIRBORNE PARTICULATES DOWNWIND FROM A URANIUM TAILINGS PILE 12-1

INTRODUCTION 12-1

EXPERIMENTAL PROTOCOL 12-1

Page

DISCUSSION 12-2

SUMMARY 12-3

RECOMMENDATIONS 12-3

APPENDIX A-1

RADON MEASUREMENT BY CHARCOAL SAMPLING. A-1

RADIUM, THORIUM, AND POTASSIUM RADIONUCLIDE ANALYSES. A-1

TRACE ELEMENT ANALYSIS IN AQUEOUS SAMPLES A-2

ELEMENTAL ANALYSIS OF SOILS BY X-RAY FLUORESCENCE (XRF) A-3

ELEMENTAL ANALYSIS OF SOILS BY INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS (INAA) A-4

DECAY SCHEMES FOR ^{238}U AND ^{232}Th. A-4

FIGURES

Figures - Task 5

Page

1 Poison Canyon New Mexico Mine Drainage System - Section 25 5-17

2 San Mateo Mine New Mexico, Mine Drainage Sample Site Numbers 5-20

3 Morton Ranch Mine Area, Mine Sample Numbers. 5-26

Figures - Task 7

1 Radon Flux Measurement Locations in Pit 1601 7-3

2 Radon Fluxes from the Morton Ranch 1601 Pit. 7-5

3 San Mateo Mine New Mexico, Radon Flux Survey April 1979 7-9

4 Poison Canyon Area #1 New Mexico Radon Flux Survey - April 1979 7-10

5 Poison Canyon Area #2 New Mexico Radon Flux Survey - April 1979 7-11

6 Barbara J New Mexico Radon Flux Survey April 1979 7-12

Figures - Task 8

1 Barbara J New Mexico 8-3

2 Poison Canyon New Mexico Mine Drainage System - Section 25 8-5

3 Poison Canyon Area #1 New Mexico 8-6

4 Poison Canyon Area #2 New Mexico 8-8

5 San Mateo Mine New Mexico 8-10

6 San Mateo Mine New Mexico 8-11

7 Mesa Top Shaft New Mexico 8-13

8 Morton Ranch Mine Area 8-15

9 1601 Pit Morton Ranch Wyoming. 8-17

Figures - Task 8 (continued) Page
10A 1601 Pit Gully to East 8-18
10B 1601 Pit Gully to South East 8-18
11 Erosion Pathway from 1601 to South Fork Box Creek 8-19
12 Uravan Area - Mine 1 8-21
13 Uravan Area - Mine 2 8-22
14 Uravan Area - Mine 3 8-23
15 Uravan Area - Mine 4 8-24
16 Uravan Area - Mine 5 8-26
17 Uravan Area - Mine 6 8-27
18 Boulder Area - Mine 7 8-28
19 Boulder Area - Mine 8 8-29
20 Boulder Area - Mine 9 8-30
21 Boulder Area - Mine 10 8-32

Figures - Task 9

1 1601 Pit (Inactive) Morton Ranch Uranium Mine. 9-2
Douglas, Wyoming, Gamma Survey - April 1979
2 1601 Pit (Inactive) Morton Ranch Uranium Mine. 9-4
Douglas, Wyoming, Gamma Survey - April 1979
3 1601 Pit (Inactive) Morton Ranch Uranium Mine. 9-5
Douglas, Wyoming, Gamma Survey - April 1979
4 1601 Pit (Inactive) Morton Ranch Uranium Mine. 9-6
Douglas, Wyoming, Gamma Survey - April 1979
5 Comparison of Pressurized Ion Chamber (PIC). 9-7
Readings and Shielded NE 148A Scintillometer
Readings (45° Leg of Morton Ranch 1601 Pit)
6 San Mateo Mine New Mexico Gamma Survey - 9-10
April 1979
7 San Mateo Mine New Mexico Gamma Survey of Water. 9-11
Shed - May 1979

Figures - Task 9 (Continued)

		Page
8	Mesa Top Shaft New Mexico Gamma Survey - April 1979	9-14
9	Poison Canyon Area #1 New Mexico Gamma Survey April 1979	9-15
10	Poison Canyon Area #2 New Mexico Gamma Survey April 1979	9-17
11	Barbara J New Mexico Gamma Survey - April 1979	9-18
12	Uravan Area - Mine 1	9-20
13	Uravan Area - Mine 2	9-21
14	Uravan Area - Mine 3	9-22
15	Uravan Area - Mine 4	9-23
16	Uravan Area - Mine 5	9-24
17	Uravan Area - Mine 6	9-26
18	Boulder Area - Mine 7	9-27
19	Boulder Area - Mine 8	9-28
20	Boulder Area - Mine 9	9-29
21	Boulder Area - Mine 10	9-30

Figures - Task 12

1	Site Locations for Airborne Particulate Collection	12-4

TABLES

Tables - Task 1

Page

1 U, Th, and Ra Radionuclides in Windblown Dust Upwind and Downwind from an Open Pit Uranium Mining Operations 1-2

2 Major and Trace Elements in Air Particulates Collected Near an Ore Pile 1-4

Tables - Task 2

1 Radon-222 Concentrations in Water and Air from Underground Uranium Mine Vents 2-6

2 Air and Water Flow Rates from Mine Vents 2-7

3 Comparison of Radon Emission Rates Associated with Water and Air from Underground Uranium Mine Vents 2-8

4 Major and Trace Element Concentrations in Waterborne Particulates 2-9

5 Major and Trace Elements Concentrations in Airborne Particulates 2-10

6 Waterborne Particulate Emission Rate 2-11

7 Airborne Particulate Emission Rate 2-12

8 Thorium-228, Radium-226, and Potassium-40 in Mine Vent Water and Aqueous Particulates at Exhaust Vents 2-13

9 Thorium-228, Radium-226, and Potassium-40 in Airborne Particulates from Underground Mine Vents - April 1979 2-14

Tables - Task 3

1 Thorium Content of Overburden, Subore, and Ore 3-3

Tables - Task 4

1 Water Sample Descriptors 4-5

2 Elemental Composition of Aqueous Mine Effluents 4-6

3 Thorium-232, Radium-226, Radon-222, and Potassium-40 in Pond Waters Removed from Underground and Open Pit Mines 4-15

Tables - Task 5

Page

1 Sample Descriptors 5-2

2 Radionuclides in Soil and Drainages Around Uranium Mills 5-5

3 Radionuclide Concentrations in Drainage Waters from Uranium Mines 5-7

4 Elemental Concentrations in Soil Samples from Abandoned Mine Drainage Areas 5-8

5 Water Samples from EPA Uranium Mine Study 5-14

6 Major and Trace Elements in Waterborne Particulates. 5-15

Tables - Task 6

1 Radon Concentrations at Mesa Top Mine Shaft and Escape Vent 6-3

2 Vent Samples at Mesa Top Mine. 6-4

3 Radon Emissions from Mesa Top Shaft 6-5

4 Ambient Air Concentrations Adjacent to Mesa Top Shaft 6-7

5 Radon Concentration Patterns at Barbara J No. 3 Mine 6-10

6 Radon Emissions at the Barbara J Mine. 6-12

7 Maximum Potential Observed Radon Emissions at the Barbara J Mine 6-13

Tables - Task 7

1 Radon Exhalation from Ore, Subore, and Overburden at Morton Ranch, 1601 Pit, April 1979 7-4

2 Radon Emission Rates from 1601 Pit Area, Morton Ranch . . . 7-5

3 Radon Flux Measurements (Charcoal Canister) 7-7

Tables - Task 8

1 Physical Parameters for the Inactive Mines Studied in Wyoming, New Mexico and Colorado 8-2

Tables - Task 9 Page

1 A Comparison of Radon Flux to Dose Readings as Measured by the EPA NE 148A Scintillometer 9-9

Tables - Task 10

1 Sample Descriptors 10-3

2 Radionuclide Concentrations in Soils 10-5

3 Uranium-238 and Radium-226 Concentration and Ratios at Inactive Uranium Mining Sites 10-13

4 Trace Element Composition of Soil, Waste and Ore from Inactive Wyoming and New Mexico Open Pit Uranium Mines 10-14

5 Trace Element Composition of Soil, Waste and Ore from Inactive Wyoming and New Mexico Open Pit Uranium Mines 10-20

Tables - Task 11

1 Trace Elements in Uranium Mill Effluent and in Tailings Leachate 11-4

2 Radionuclide Concentrations in Uranium Tailings Solutions 11-5

3 Trace Elements in Uranium Mill Effluent and in Tailings Leachate 11-6

4 Radionuclide Concentrations in Uranium Tailings Solutions Collected in October 1979 11-7

Tables - Task 12

1 Sierra Impactor Sampling Parameters - Homestake Partners, Grants, NM 12-5

2 Trace Element Analysis of XRF of Sierra Cyclone Separated Dust Downwind of Homestake Partners Tailings Pile, Grants, New Mexico, 5/15/79 to 7/9/79 12-6

3 Trace Element Analysis by Neutron Activation on Sierra Impactor Samples of Aerosols Downwind of Homestake Partners Tailings Pile, Grants, New Mexico, 5/15/79 to 7/9/79 by XRF 12-8

Tables - Task 12 (continued) Page

4 Radionuclide Concentration in Aerosols Collected by Sierra Impactors as a Function of Particle Size 12-16

PNL-3069, Part II
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AN ENVIRONMENTAL STUDY OF ACTIVE AND INACTIVE URANIUM MINES, MILLS, AND THEIR EFFLUENTS

Pacific Northwest Laboratory
Richland, Washington 99352

ABSTRACT

The purpose of this short-term study has been: 1) develop broad bases; and 2) obtain new information relevant to the needs of the Environmental Protection Agency. These data bases are required to provide information for the Clean Air Act and Uranium Mill Tailings Radiation Control Act. This report, Part II, deals specifically with twelve tasks associated with the Uranium Mill Tailings Radiation Control Act. They are:

Task 1. Physical and Chemical Characterization of Resuspended Materials from Ore, Subore, and Overburden Material

Task 2. Radon and Other Constituents in Mine Water and Exhaust Vents

Task 3. Thorium Content of Overburden, Subore, and Ore

Task 4. Analysis of Pollutants in Aqueous Effluents and Wastes

Task 5. Trace Elements and Radionuclides in Surface Run-Off from Ore, Subore, and Overburden Piles

Task 6. Radon Emission from Inactive Underground Uranium Mines

Task 7. Radon Exhalation from Ore, Subore, and Overburden from an Inactive Uranium Mine

Task 8. Site Mapping

Task 9. Gamma Mapping

Task 10. Soil Sampling

Task 11. Chemical Constituents of Mill Tailings Leachates

Task 12. Chemical and Radiochemical Composition of Airborne Particulates Downwind from a Uranium Tailings Pile

Due to the complexity and the number of tasks, each task has its own summary and recommendation section. However, an executive summary has

been used which provides the total interpretation and recommendations of all twelve tasks.

EXECUTIVE SUMMARY

TASK 1 - PHYSICAL AND CHEMICAL CHARACTERIZATION OF RESUSPENDED MATERIALS FROM ORE, SUBORE, AND OVERBURDEN MATERIAL

A complete chemical and physical property study of aerosol material in the vicinity of an open pit uranium mine could not be completed under the field conditions available during the time frame involved in generating this specific data base. However, the study found that under wind conditions from 1-3 meters/sec that most particles were of a fine size passing through all stages of a large volume Anderson impactor. The 0.45 micron back-up filter collected over 50% of the mass. There was little if any contribution to the atmospheric particulate material load from the uranium mining operation.

Recommendations

In the generation of the broad data base involved in this program, the dictates of the study necessitated collection of field samples under short time frame constraints. This task, physical and chemical characterization of resuspended materials from ore, subore, and overburden material, could not be adequately completed due to the light winds and inactive operation at the mine facility during the required study period. It is therefore recommended that a complete physical and chemical characterization of resuspended materials from ore, subore, and overburden material be initiated over a sufficiently long time frame that would allow wind conditions from 1-20 meters/sec to be studied under both active and inactive mine operating conditions.

TASK 2 - RADON AND OTHER CONSTITUENTS IN MINE WATER AND EXHAUST VENTS

Radon-222, ^{228}Th, ^{226}Ra, ^{40}K, and the major and trace element concentrations were studied in mine waters and exhausts from five vents in the Ambrosia Lake, New Mexico region. The concentrations of ^{222}Ra in water range from 5% to 16% of the concentrations in air from the same vent. In these samples either the water had a low radon content when it entered the vent and failed to reach equilibrium with mine air in the vent before discharge or a partial loss occurred because of rapid exchange with ambient air. Most radon is emitted in the air discharge with little being found in the water fraction. The waterborne particulates from the vent are calcium aluminum silicates with iron as the secondary specie. Trace elements lead, uranium, and transition metals were detected. The major constituents in the airborne particulates were sulfur, chlorine, and calcium. Small amounts of iron and zinc were measured. Most elements were below parts-per-million limits. In general, waterborne particulates account for only a very small fraction of the total particulate emission due to large airborne emissions. A study of ^{228}Th, ^{226}Ra, and ^{40}K indicated that all airborne particulates from aqueous or airborne sources were below the maximum permissible concentrations for insoluble species in water and in air.

Recommendations

During generation of this data base no specific surprises were found with respect to radon, radon daughters and other trace inorganic constituents in mine waters and exhaust from mine vents. The task, however, investigates only five vents from one specific area in the Ambrosia Lake, New Mexico region. Vents containing low water emission, high water emission, and low air flow rates should be studied in order to apply the data base generated in this study to a large variety of vent conditions in existence in the United States Mining industry.

TASK 3 - THORIUM CONTENT OF OVERBURDEN, SUBORE, AND ORE

Natural ^{232}Th was not found to be present in elevated concentrations in any of the ore, subore, wastes, or soils associated with uranium mining operations. Its average concentrations were 1.3 pCi/g in the Morton Ranch, Wyoming area, and 0.5 pCi/g in the Grants, New Mexico region. These concentrations are typical of those found in natural earth crust materials which do not show mineralization of thorium. It seems that these observations are sufficient to establish that the ^{232}Th chain is not likely to be a significant contributor to the radiological hazard associated with uranium mining.

Recommendations

This brief study created a small data base for the investigation of the thorium content in overburden, subore, and ore. However, since samples were analyzed from only two states, it does not represent the entire uranium industry. Samples should be taken in areas containing ore, subore, and overburden at other mining sites within the United States to verify that the conclusions derived from these data are applicable to a broad-range uranium industry. Although it is outside the range of this particular study, the nonuniformity in the ^{238}U/^{226}Ra chain should be investigated. This disequilibrium cannot be explained with the limited data base accumulated here.

TASK 4 - ANALYSIS OF POLLUTANTS IN AQUEOUS EFFLUENTS AND WASTES

Molybdenum, selenium, arsenic, and nickel were found in a soluble form. Aluminum was predominantly insoluble. The transition metals did not exhibit consistent behavior. Selenium appeared to represent the most serious potential problem of the elements measured since elevated selenium was found in the soluble fraction. Lead and cadmium concentrations were in general below drinking water standard levels. Chromium and barium did not exceed the U. S. drinking water standards. The analyses of radionuclides indicated that ^{232}Th, ^{226}Ra, ^{222}Rn, and ^{40}K concentrations were far below the standards for particulate and soluble radionuclides in public waters. The quantity of radon dissolved in water exhausting from underground mines was found to be an extremely small fraction of the total radon escapement from the vents.

Recommendations

The data base created in this study represents only two limited areas in the uranium mining industry--the Ambrosia Lake area of New Mexico and the Morton Ranch area in Wyoming. Further studies are required to measure the radioactive and trace element compositions of aqueous effluents and wastes in other areas of the uranium mining industry. In addition, these studies primarily emphasized surface drainages and runoffs; this was not a study of the hydrologic movement of underground trace elements or radionuclides. A study should be completed to encompass the movement of trace elements and radionuclide materials from areas occupied by the uranium mining and milling industry.

TASK 5 - TRACE ELEMENTS AND RADIONUCLIDES IN SURFACE RUN-OFF FROM ORE, SUBORE, AND OVERBURDEN PILES

Data on trace elements and radionuclides from ore, subore, and overburden piles in surface run-off are discussed in this task and in Task 10. Two mine drainage areas in the Grants, New Mexico area and one area in Wyoming were studied. The chemical analyses and radiochemical studies of soils, water samples, and waterborne particulates indicate that the various locations are site specific and results must be considered individually for the specific areas. In the Poison Canyon, New Mexico region, ^{232}Th levels in soils were essentially constant and the lowest encountered at any site. Radium-226 levels were not significant in a watershed near, above and below the mine. Uranium-238 concentrations were 2 pCi/g in all samples. In Poison Canyon most of the trace element concentrations were not significantly higher downstream of the mine piles than upstream background levels. One high ^{226}Ra measurement correlated with an elevated barium and calcium content adjacent to a waste pit; however, no significant contamination from the underground site was detected. At the San Mateo site in New Mexico, the ^{232}Th concentrations in the waste and heap leach composite samples were slightly elevated over that taken from the drainages, but in general all samples contained thorium at approximately ambient background levels of 0.55 pCi/g. Radium-226 concentrations were 117 pCi/g in the waste composite and 127 pCi/g in a heap leach composite. Approximately 700 meters from the heap leach area, the ^{226}Ra content of the soils was not significantly different from background. Variations in trace element concentrations in samples collected upstream and downstream from the mine areas at the San Mateo site indicated that their source was local. The trace elements may also be from localized mineralization or farming activities nearby. At the New Mexico inactive mine drainages, the most prominent indicator of run-off from aboveground mineral storage was ^{226}Ra content of the stream bed. It was apparent that its concentrations were almost 2 orders of magnitude higher in source materials than occurred in background soils. Elements such as uranium and selenium also had a large concentration gradient. These gradients all decreased going downstream from specific mine sites. At Poison Canyon, the ^{226}Ra concentration diminished to twice background in a distance of 100 meters, while at the San Mateo site the twice background distance was about

400-500 meters. At the Morton Ranch, Wyoming site, the radionuclides and chemical constituents show evidence of aqueous leaching based on the radium-uranium ratios. The trace element data indicate a limited transport of mine contamination with respect to uranium and to a lesser extent selenium and vanadium. It should be noted here that the samples contained some material of ore and subore origin. This is not surprising since they were collected in the immediate area near ore from the 1601 pit. No evidence was found to indicate transport of ore or subore to local stream beds such as the various forks of Box Creek. Selenium, vanadium, and arsenic, trace elements usually associated with uranium mining, are present in some cases in high concentrations in the semiactive 1704 pit seep but are near ambient levels in water taken in Box Creek. The data indicate that mine-related pollutants were not observed at significant distances from their source; rather they were confined to the immediate environs of the mining operation.

Recommendations

This study generated a rather large data base for inactive mining sites in two states. Further work at sites receiving higher precipitation should be completed. Selected soil sampling, as well as water sampling, techniques should be used. This study was unable to sample trace elements or radionuclides in any surface run-off from ore, subore, or overburden piles as a function of high rainfall rate or the melting snow.

TASK 6 - RADON EMISSION FROM INACTIVE UNDERGROUND URANIUM MINES

Radon emission rates from two inactive underground mines were measured. The first, Mesa Top, is an inactive underground mine of large size; the second, Barbara J, of Poison Canyon is relatively small. The Mesa Top Mine which connects with other inactive and active mines is a significant radon source with an emission rate of about 1 Ci/day. High radon concentrations were measured a few meters downwind from the shaft. The radon emission rate from the Barbara J was relatively small with radon concentration peaks only up to 12 pCi/ℓ measured at the mine site. The presence of two dissimilar mines such as the Barbara J and the Mesa Top within a mile of one another indicate the difficulty of establishing criteria for radon emissions from typical inactive underground mines.

Recommendations

During this study of radon emissions from inactive underground uranium mines, ten mines were evaluated in the Grants, New Mexico, uranium belt. None of the mines completely satisfied inactive criteria or fulfilled a requirement of isolation from other mines. This is indicated by the tremendously dissimilar data generated for the two "inactive" mines. This data base further indicates that studies should include environmental measurements to be taken during stagnate air conditions to observe local maximum effects. In addition, studies of a large number of inactive mines must be completed so that typical cases can be determined. It appears that given the proper configuration, an abandoned mine may represent a significant local source of radon unless steps are initiated to seal such mines effectively.

TASK 7 - RADON EXHALATION FROM ORE, SUBORE, AND OVERBURDEN FROM AN INACTIVE URANIUM MINE

Radon fluxes measured at inactive uranium mine sites were at times highly variable, even at different spots on a location. For example, at the waste pile at the San Mateo mine, variations of nearly 3 orders of magnitude were found.

The rate of radon emission from the 1601 pit and surrounding disturbed surface at Morton Ranch, Wyoming, was calculated to be $\sim 3.5 \times 10^6$ pCi/sec, including four ore piles that contributed about one-half of the total. This corresponds to a radon flux of $\sim 3 \times 10^{-3}$ pCi/sec/cm^2, exclusive of the ore piles, a value that might be reasonable to apply to obtain an estimate of radon emission from other inactive mine sites.

Recommendations

If one assumes the primary purpose of measuring radon exhalation from ore, subore, and overburden in inactive uranium mine sites to be that of settling radon emission standards, then more studies at a variety of sites must be completed to generate typical radon emission values for ore, subore, and overburden spoil at the sites. The study would not require extensive sampling at each site but would allow samples at many sites to be taken to achieve a gross estimate of the radon emission at inactive uranium mining sites.

TASK 8 - SITE MAPPING

Those mines surveyed in the Uravan area are probably typical of the many inactive uranium mines in that area. Most of the mines are relatively small and are underground. Wind and water erosion is occurring at all of the mines inspected, and all of the entries were open except where noted.

Ore haulage losses have occurred on the roads. In addition, mine wastes have been used for road ballast. The lands in the mining areas are used for grazing.

Exploratory drilling is abundant in the survey area and the resulting land damage is extensive. Little or no reclamation of drill sites was observed.

Mines 8 through 10 were surveyed near Jamestown, Colorado. These mines, although small, are typical of this area. Although uranium was not principally produced by many of these mines, the mine wastes are generally radioactive.

Mine wastes were used as fill for the Jamestown Park (210 acres) and are producing exposure rates of 40 to 100 μR/hr in that area. It appears that some dwellings may be built on or near the mine wastes. Surface and groundwater contamination from the old mining activities is likely.

Recommendations

Not appropriate.

TASK 9 - GAMMA MAPPING

Gamma surveys of inactive uranium mines were conducted using an NE-148 scintillometer and a pressurized ion chamber (PIC) obtained from the EPA-Las Vegas group. Six inactive uranium mine areas were studied which include Morton Ranch, Wyoming, and the San Mateo, Mesa Top, Poison Canyon Area #1, Poison Canyon Area #2, and Barbara J #3, New Mexico. Also included in this section are measurements made by walk-through at ten inactive mines in the Colorado area by the Environmental Protection Agency personnel.

At the Morton Ranch mine, the gamma survey showed decreasing dose levels as one moved outward from the mine. On some sectors, there was a dose increase as one moved away from the inactive mine which was related to natural outcroppings of uranium ore. In this area, radioactivity is associated with natural outcroppings rather than contamination associated with any mining operation, wind erosion, or wind/water transport of ore material for any distance. A comparison was made of radon flux measured at the Morton Ranch site in Part II, Tasks 6 and 7, with the gamma survey completed in this study. It was rather surprising that the ratio of dose in μR/hr to radon flux varied almost 100-fold. This would indicate that μR readings do not provide a good indication of the radon flux in this area of open pit inactive uranium mines. Shielded dose readings ranged from 11.5 μR/hr to 60 μR/hr away from the inactive pit. Dose readings in the pit varied from 17.5 μR/hr to 68 μR/hr.

The gamma dose survey of the San Mateo mine area indicated that the main waste pile ranged from 35 to 300 μR/hr with heap leach ponds varying from 95-170 μR/hr and a south entry road reading from 13-118 μR/hr. The gamma dose field readings diminished steadily with distance from the waste pile area in the San Mateo mine region with background readings obtained 460 meters from the pile.

Gamma dose measured at the Mesa Top mine ranged from a low of 25 μR/hr at the edge of the waste to a high of 290 μR/hr on the subore pile.

The Poison Canyon #1 mine area had dose readings ranging from 50-165 μR/hr with backgrounds of 25 μR/hr. At the Poison Canyon #2 mine area, most gamma dose readings were approximately 30 ± 5 μR/hr. The surveys indicated local hot spots within the pit and waste site areas. Most readings adjacent to the pits and waste piles were within a factor of 2 of background levels. At the Barbara J mine site, background levels away from the waste piles ranged from 12-15 μR/hr. The highest readings on the waste piles were 170 μR/hr.

Those mines surveyed in the Uravan area are probably typical of the many inactive uranium mines in the area. Most of the mines are relatively small and are underground. Wind and water erosion is occurring at all of the mines inspected and all of the entries were open except where noted.

Ore haulage losses have occurred on the roads. In addition, mine wastes have been used for road ballast. The ore losses and mine wastes used on the roads probably became airborne as some of the large quantities of dust produced by ore hauling equipment. The lands in the mining area are used for grazing. Some enhanced uptake of radioactive materials and trace metals by cattle is probably occurring.

Exploratory drilling is abundant in the survey area and the resulting land damage is extensive. Little or no reclamation of drill sites was observed.

Three mines were surveyed near Jamestown, Colorado. These mines, although small, are prevalent in this area. Although uranium was not principally produced by many of the mines, the mine wastes are generally radioactive.

Mine wastes were used as fill for the Jamestown Park (34 km^2) and are producing exposure rates of 40 to 110 μR/hr in that area. Some evidence indicates that some dwellings may be built on or near the mine wastes. Surface and groundwater contamination from the mining activities is likely.

Recommendations

Not applicable.

TASK 10 - SOIL SAMPLING

The trace element concentrations at the inactive uranium mining sites show a wide variation in soil and waste rock which is generally unrelated to mining activities. There are, however, some definite correlations between uranium and certain trace elements in ore samples. For example, high uranium concentrations were associated with high concentrations of molybdenum, vanadium, arsenic, and possibly copper. Radionuclide concentrations in environmental soils varied by orders of magnitude as might be expected and seem to be the best indicator of pollution from the mining activities. Uranium-238 to ^{226}Ra ratios differed by as much as 100-fold which seems unreasonably large, and we therefore question whether this reflects inhomogeneity in sample aliquots selected for ^{238}U and ^{226}Ra measurements rather than actual disequilibrium. Except for the specifically selected uranium ore sample, radioactivity in all of the samples was rather small and would therefore not seem to constitute a major environmental contamination problem.

Recommendations

It must be recognized that this study was conducted over a very short period of time and a very limited amount of time was available for the planning and sampling operation, as well as for the analyses. We therefore recommend that these observations be considered as preliminary and that prior to formulation of rigid guidelines for the deactivation of mine sites, more detailed studies of this type should be conducted. These could be based on the information gathered in this work and aimed specifically at determining radionuclide and trace element distribution in the environs of a fairly large inactive uranium mining site.

TASK 11 - CHEMICAL CONSTITUENTS OF MILL TAILING LEACHATES

The concentrations of the trace elements and radionuclides which are soluble in the tailings slurries from alkaline and acid leach mills have been compared with seep solutions from the respective tailings piles. It was observed that the seep solutions have concentrations which are comparable to those in the input slurries but may actually be higher as a result of the heap leaching process which takes place within the tailings pile. It also appears that as these seep solutions move into the underlying soil, they will quickly saturate the sorption sites in the soil and that the solutions moving into the groundwater table will eventually have a composition similar to that of the input slurry.

Recommendations

We recommend that a study be carried out which would carefully compare the concentrations of dissolved trace elements and radionuclides in input slurries, seepage solutions, and groundwater for active uranium tailings piles from both alkaline leach and acid leach uranium extraction processes.

TASK 12 - CHEMICAL AND RADIOCHEMICAL COMPOSITION OF AIRBORNE PARTICULATES DOWNWIND FROM A URANIUM TAILINGS PILE

From this limited study, it is evident that there is a substantial contribution of tailings material to the natural aerosol at distances of 1000 to 4000 meters downwind from this dry tailings pile. This is clear both from the radionuclide composition and from key trace elements which are characteristically high in the tailings material. Also, a major fraction of resuspended tailings material is associated with particles of <0.5 microns.

Recommendations

Since the data obtained from this task were taken under a wide integrating range of wind speeds, we recommend that further measurements be made as a function of wind speed to determine what the actual suspension of tailings material produces in the way of aerosol concentrations downwind from tailings piles of this type. We also recommend that the data developed in this report on trace elements be further analyzed and compared with the trace element composition of tailings material and of ambient soil so that with this information a more quantitative estimate of resuspension of both radioactive and trace elements can be obtained.

TASK 1

PHYSICAL AND CHEMICAL CHARACTERIZATION OF RESUSPENDED MATERIALS FROM ORE, SUBORE, AND OVERBURDEN MATERIAL

INTRODUCTION

The objective of this study has been to determine the chemical and physical properties of aerosol materials in the vicinity of an open pit uranium mine. It was suspected that there would be a substantial difference in the radionuclides present in aerosols downwind of such an operation relative to those upwind, and that there also might be differences in the trace elements which would reflect the composition of the ore. To determine the magnitudes of these differences, several sets of high volume cascade impactor samples were collected at the Morton Ranch mine. In one experiment, the samples were collected approximately one mile upwind and one mile downwind from the operating open pit during the period April 20 to April 24. Unfortunately, the wind velocities during these time periods were extremely light and very small amounts of material were collected on the various stages of the impactor.

DISCUSSION

As indicated in Table 1, the dust loading only amounts to between 33 and 73 μg/ℓ of air. The samples collected during daylight and night-time intervals during the sampling period were composited for each site to provide enough total activity to permit analysis of a group of radionuclides as shown in Table 1. These measurements were all made by radiochemical separation followed by alpha energy analysis and thus provide good precision for the relative amounts of each isotope. It is important to recognize that there seems to be little or no contribution from the uranium mining operation, i.e., the upwind and downwind samples show comparable concentrations

TABLE 1

U, Th, AND Ra RADIONUCLIDES IN WINDBLOWN DUST UPWIND AND DOWNWIND FROM AN OPEN PIT URANIUM MINING OPERATIONS

Sample Location	Upwind (SW)	Upwind (SW)	Downwind (NE)	Downwind (NE)
Time of Sampling	Day	Night	Day	Night
Volume (m³)	1451	2118	754	2295
Dust Loading (μg/m³)	54	33	73	49
	pCi/gram			
^{228}Th	5.88 ±.79	5.33 ±.46	1.20 ± .35	1.08 ±.27
^{230}Th	4.73 ±.71	4.61 ±.43	4.74 ±1.22	1.93 ±.48
^{232}Th	3.29 ±.59	3.93 ±.40	3.91 ± .37	2.48 ±.64
^{238}U	2.01 ±.27	2.28 ±.31	2.04 ± .28	1.55 ±.21
^{234}U	3.23 ±.37	3.13 ±.37	2.01 ± .39	1.80 ±.27
^{226}Ra	1.39 ±.81	4.43 ±.92	2.13 ± .51	2.22 ±.26

and, in fact, the downwind samples may be even lower in concentrations.

During a second time period, May 23 through May 25, cascade impactor samples were collected about 19 m downwind of an ore stockpile. Again the winds were extremely light and there was little vehicle traffic. The very clean air conditions made the particle size distribution abnormally depleted of coarse particles leaving most of the mass on the back-up filter. The dust loading on the back-up filter amounted to $14\mu g/\ell^3$ for the 2552 m^3 sample volume and exceeded the amount on all other stages combined.

The trace element analyses performed on these samples are summarized in Table 2 and illustrate the predominance of particulate mass on the back-up filter. As usually observed in both urban and remote areas, elements such as nickel, copper, zinc, arsenic, bromine, and lead, and to a lesser extent sulfur, uranium, chromium, manganese, iron, and selenium, show enrichment in the smaller size fractions. Uranium was only observed in the largest fraction and presumably came from resuspended ore material. Since winds were light and variable in direction, this sample represents both overburden and ore resuspension, as well as longer-range transport of fine particulates. The high lead and bromine concentrations are indicative of automobile exhaust. Some of the lead and arsenic could also result from a large fossil-fueled power plant some 20 to 30 miles away.

SUMMARY

A complete chemical and physical property study of aerosol materials in the vicinity of an open pit uranium mine could not be completed under the field conditions available during the time frame involved in generating this specific data base. However, the study found that under wind conditions from 1-3 meters/sec that most particles were of a fine size passing through all

TABLE 2. Major and Trace Elements in Air Particulates Collected Near an Ore Pile*

(ng/m^3)

	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Ga	As	Se	Br	Rb	Sr	Zr	Mo	Hg	Pb	U
Stage 1	940	<70	<60	30	43	61	7	<1	<0.7	1.6	82	0.30	3.9	1.0	<0.3	<0.4	<0.3	7.6	<0.5	<0.8	<0.9	<1	<1	4.3	2.6
±	110			10	3	3	1			.3	1	.16	.2	.2				.2						.6	1.1
Stage 2	590	<70	<60	30	40	87	8	<1	<0.7	1.3	81	<0.3	13.7	1.3	<0.3	1.4	<0.3	9.9	<0.5	<0.7	<0.9	<1	<1	8.6	<2.0
±	90			10	3	3	1			.3	1		.4	.2		.3		.2						.6	
Stage 3	500	<60	<60	<30	31	57	8	<1	<0.6	0.9	77	<0.2	13.5	1.1	<0.3	0.8	<0.3	10.0	<0.4	<0.7	<0.9	<1	<1	10.5	<2.2
±	80				3	3	1			.3	1		.4	.2		.2		.2						.6	
Stage 4	520	<70	<70	<30	33	62	7	<1	<0.6	1.2	85	<0.3	40.	1.8	<0.4	1.9	<0.3	12.4	<0.5	<0.7	<0.9	<1	<1	18.3	<1.5
±	90				3	3	1			.3	1		1.	.2		.3		.3						.7	
Stage 5	320	<70	270	<30	32	40	5	<1	1.4	1.0	70	0.8	48.	2.0	<0.4	2.7	0.3	13.0	<0.4	<0.7	<0.8	<1	<1	20.4	<2.2
±	70		40		3	2	1		0.3	.3	1	.1	1.	.2		.3	.1	.3						.7	
Backup	2900	<300	<400	<170	230	300	51	6	<3	9.0	559	2.9	91.	10.0	<1.7	30	1.4	151	<2	3.3	<3	4.3	<4	273	<7
±	400				10	10	4	2		1.0	6	.6	2.	1.0		2	.6	2		1.4		1.9		4	

*Stage 1, >7.2 µm; Stage 2, 3.0-7.2 µm; Stage 3, 1.5-3.0 µm; Stage 4, 0.95-1.5 µm; Stage 5, 0.49-0.95 µm; Backup, <0.49 µm.

stages of a large volume Anderson impactor. The 0.45 micron back-up filter collected over 50% of the mass. There was little if any contribution to the atmospheric particulate material load from the uranium mining operation.

RECOMMENDATIONS

In the generation of the broad data base involved in this program, the dictates of the study necessitated collection of field samples under short time frame constraints. This task, physical and chemical characterization of resuspended materials from ore, subore, and overburden material, could not be adequately completed due to the light winds and inactive operation at the mine facility during the required study period. It is therefore recommended that a complete physical and chemical characterization of resuspended materials from ore, subore, and overburden material be initiated over a sufficiently long time frame that would allow wind conditions from 1-20 meters/sec to be studied under both active and inactive mine operating conditions.

TASK 2

RADON AND OTHER CONSTITUENTS IN MINE WATER AND EXHAUST VENTS

INTRODUCTION

As a part of the Uranium Mill Tailings Radiation Control Act, studies and data base generation are required to evaluate the radon and trace metal constituents being emitted from operating mines through mine water and exhaust vent particles. A study of the type and quantity of radioactive and nonradioactive emissions in these waters and exhaust vents was initiated at five vents in the Ambrosia Lake, New Mexico region. These five vents were selected because they were discharging water droplets with the vented air. The selected vents were all receiving water from aquifers located above the level of active mining, which enters the vents through leaks in the casing. It is carried upward by the air stream and discharged through the vent fan. Since the exit velocity of these vents is typically of the order of tens of feet per second, the water spray can be thrown 50 to 100 feet. A great deal of this thrown water is in the form of fine mists which evaporate before striking the ground. These mists tended to pass through water traps and collect with dry particulates. At the vent itself, a large fraction of the water collects on interior vent structures and runs from the vent outlet in a steady stream.

EXPERIMENTAL PROTOCOL

The quantity of water flowing from the vent was measured by quantitative collection for a known time interval. The airborne water was collected with a large impinger constructed from a metal elbow which discharged into a 30-gallon can. The elbow was held facing the air stream for a known interval of time in a representative area of the discharge. Air and water were thus forced to make a right angle turn downward into the can where the larger droplets were collected by impaction. The mist and finer droplets were not collected. The total airborne water in the exhaust air was estimated from the relative areas of the vent opening and the sampling duct. This quantity, when added to the volume of run-off water, yielded an estimate of total water discharged within ±50%.

Since water spray was expected to be an effective scavenger for particulates in the air stream, samples of the vent run-off water were collected and filtered in the field. To measure the airborne particulates, the air was first passed through two six-gallon polyethylene containers, which acted as impingers to trap the larger water droplets, and was then filtered through Microsorban filters. Additional water samples were placed in aluminum cans with tedlar plastic seals in the lids for laboratory measurement of the total radon content by multidimensional gamma-ray spectroscopy. Filtered air samples were collected in internally-coated scintillation flasks to measure the airborne radon content.

DISCUSSION

The radon concentration in air and water from these vents is shown in Table 1. The ^{222}Ra concentration in exhaust water from the mine vents varied from 110 - 300 pCi/ℓ of water. Radon-222 in air from the mine vents varied from 860 - 3,440 pCi/ℓ of air. The concentrations of radon in water ranged from less than 5% to 16% of the concentrations in air from the same vent. These values correspond to 20% to 64% of the equilibrium concentration expected at 20°C as tabulated in Reference 1. Although groundwater is often supersaturated with radon, in these samples either the water had a low radon content when it entered the vent and failed to reach equilibrium with mine air in the vent before discharge, or a partial loss occurred because of rapid exchange with ambient air while the sample was being collected. In all cases when the flow rate corrections given in Table 2 are considered, the radon in the water fraction represents a miniscule fraction of total radon discharged, as shown in Table 3. The ratio of the ^{222}Ra emitted in air to that emitted in water from the same vent varied from <4,000 to 600,000.

Elemental analyses of waterborne and airborne particulates from these vents were performed using a nondispersive X-ray fluorescence technique. The concentrations of elements as particulates in the vent water are shown in Table 4. The major constituents of these particulates appear to be calcium aluminum silicates with a second fraction consisting of iron, presumably as the oxide or hydrated oxide which probably originates as corrosion products from the metal vent pipe. There are also significant quantities of the Group II elements, apparently largely as sulfates. Among trace elements, the major components are lead, uranium, and the transition metals (titanium, vanadium, chromium, manganese, nickel, copper, zinc). The elevated bromine content, along with elevated sulfur, seen at 30W-V4 and 35-V3 may indicate traces of water present on the filters since these components should be primarily in the soluble fraction.

The major constituents in the airborne particles were sulfur, chlorine, and calcium, as shown in Table 5. Smaller amounts of iron and zinc were noted. Some positive values were obtained for copper, strontium, and lead, but in general, concentrations of most elements were below detection limits. This fraction appears to be dominated by the soluble salts which would be present in airborne mists. At Section 36-V2 where these water-soluble constituents are not positive, there is very little water being thrown from the vent. The iron and lead emitted as airborne particulates were higher at this vent.

In Tables 6 and 7 the emission rates of waterborne and airborne particulates, respectively, are shown. Because of the much lower rate of water discharge, waterborne particulates account for only a small fraction of the total particulate emission. The sole exception is iron, in which case the airborne particulates accounted for as little as 2% to as much as 19 times the quantity discharged as aqueous particulates. A hundred to a thousand times more sulfur and chlorine were discharged with airborne particulates when compared with water insoluble fractions. However, the compounds of these elements are most likely water soluble in which case a very low particulate concentration in water would be expected. Also, any dried salts from water mists which are collected as airborne particulates would cause that component to appear high. The airborne-to-waterborne ratios for the trace elements zinc, lead, and uranium were at least 15-fold higher in the airborne samples. The important feature of these data is that, regardless of the mechanism, the major portion of all the elements leaving the mine exhaust is associated with the airborne particulates.

The radionuclides ^{208}Tl, ^{214}Bi, and ^{40}K were measured in these air and water filters using multidimensional gamma-ray spectroscopy.[2] These filters had been hermetically sealed for an interval before counting so that results could be used to determine the ^{228}Th, ^{226}Ra, and ^{40}K content. Essentially all of the results from these instrumental analyses, as shown in Tables 8 and 9, were at or below the very sensitive detection limits for the instruments. These levels are extremely low compared to MPC's for insoluble species in water and less than the MPC's for air, per 10 CFR 20, Appendix B, 1978 (see Tables 8 and 9).

SUMMARY

Radon-222, ^{228}Th, ^{226}Ra, ^{40}K, and the major and trace element concentrations were studied in mine waters and exhausts from five vents in the Ambrosia Lake, New Mexico region. The concentrations of ^{222}Ra in water range from 5% to 16% of the concentrations in air from the same vent. In these samples either the water had a low radon content when it entered the vent and failed to reach equilibrium with mine air in the vent before discharge or a partial loss occurred because of rapid exchange with ambient air. Most radon is emitted in the air discharge with little being found in the water fraction. The waterborne particulates from the vent are calcium aluminum silicates with iron as the secondary specie. Trace elements lead, uranium, and transition metals were detected. The major constituents in the airborne particulates were sulfur, chlorine, and calcium. Small amounts of iron and zinc were measured. Most elements were below parts-per-million limits. In general, waterborne particulates account for only a very small fraction of the total particulate emission due to large airborne emissions. A study of ^{228}Th, ^{226}Ra, and ^{40}K indicated that all airborne particulates from aqueous or airborne sources were below the maximum permissible concentrations for insoluble species in water and in air.

RECOMMENDATIONS

During generation of this data base no specific surprises were found with respect to radon, radon daughters and other trace inorganic constituents in mine waters and exhaust from mine vents. The task, however, investigates only five vents from one specific area in the Ambrosia Lake, New Mexico region. Vents containing low water emission, high water emission, and low air flow rates should be studied in order to apply the data base generated in this study to a large variety of vent conditions in existence in the United States Mining industry.

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[1] "Treatise on Analytical Chemistry",Part II, Volume 4, p. 233, J. Sedlet. Edited by I.M. Kolthoff and P.J. Elving. Interscience Publishers (1966).

[2] "An all Sodium-Iodide Anticoincidence Shielded Multidimensional Gamma-Ray Spectrometer for Low Activity Samples", N.A. Wogman, R.W. Perkins, and J.H. Kaze. N.I.M., 74, p. 197-212 (1969).

TABLE 1. ^{222}Rn CONCENTRATIONS IN WATER AND AIR FROM UNDERGROUND URANIUM MINE VENTS

^{222}Rn in Exhaust Water From Mine Vents

Vent	^{222}Rn Concentration pCi/ℓ of water
30 - V4	160 ± 90
30W - V1	270 ± 30
30W - V3	< 300
35 - V3	110 ± 50
36 - V2	< 160

^{222}Rn in Air from Mine Vents

Vent	^{222}Rn Concentration pCi/ℓ of air
30 - V4	2740 ± 220
30W - V1	1710 ± 140
30W - V3	1350 ± 110
35 - V3	860 ± 70
36 - V2	3440 ± 280

Table 2

AIR AND WATER FLOW RATES FROM MINE VENTS

ℓ/min

Vent	Air Flow	Water Flow
30 - V4	1.2×10^6	13.
30W - V1	2.2×10^6	1.7
30W - V3	2.0×10^6	2.9
35 - V3	2.7×10^6	$\sim$10.0 (2)
36 - V2	2.2×10^6	0.1

Notes: (1) Air flow, measurement accuracy estimated to be better than 15%. Water flow measurement accuracy estimated to be within 50% (see commentary).

(2) Estimated value - flow could not be measured.

TABLE 3

COMPARISON OF RADON EMISSION RATES ASSOCIATED WITH WATER AND AIR FROM UNDERGROUND URANIUM MINE VENTS

Vent	^{222}Rn Emission In Water (m Ci/day)	^{222}Rn Emission in Air (mCi/day)	$\frac{\text{Emission in Water}}{\text{Emission in Air}} \times 10^6$
30 - V4	$3.0\times10^{-3} \pm 2.4\times10^{-3}$	$4.7\times10^{3} \pm 0.8\times10^{3}$	0.6 ± 0.5
30W - V1	$6.6\times10^{-4} \pm 3.4\times10^{-4}$	$5.4\times10^{3} \pm 0.9\times10^{3}$	0.1 ± 0.07
30W - V3	$< 1.3\times10^{-3}$	$3.9\times10^{3} \pm 0.7\times10^{3}$	< 0.4
35 - V3	$\sim 1.6\times10^{-3} \pm 1.1\times10^{-3}$	$3.3\times10^{3} \pm 0.6\times10^{3}$	$\sim 0.5 \pm 0.4$
36 - V2	$< 4\times10^{-5}$	$10.9\times10^{3} \pm 1.9\times10^{3}$	< 0.004

TABLE 4

MAJOR AND TRACE ELEMENT CONCENTRATIONS IN WATERBORNE PARTICULATES

μg/liter

Vent	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn
30N-V1	310±60	1200±100	<25	78±12	<8.2	63±5	360±30	13±1	1.1±.4	1.6±.3	4.6±.4	360±20	5.2±.4	3.2±3	5.6±.4
30N-V3	2000±50	6400±500	170±40	550±50	40±10	350±30	1000±70	60±5	5.1±.9	1.8±.5	11±1	2500±100	<.25	1.8±.2	12.8±.1
30-V4	210±40	410±60	<20	83±11	<6.8	36±3	230±20	6.6±.8	<.5	.64±.20	.96±.20	310±20	<.1	0.6±.1	2.4±.2
36-V2	6700±900	1600±1000	<240	<200	<83	860±60	360±30	260±20	43	13±3	170±12	11000±1000	3.4±.7	10±1	130±9
35-V3	1300±200	3000±300	<64	510±50	34±10	170±10	740±50	28±2	5.9±.8	1.4±.5	13±1	2000±100	.26±.12	1.4±.1	15±1

Vent	Ga	As	Se	Br	Rb	Sr	Y	Zr	Nb	Mo	Sb	Ba	Hg	Pb	U
30N-V1	<.1	.3±.1	.26±.04	.11±.03	.21±.05	9.8±0.8	<.2	.7±.1	<.2	.3±.1	<1.4	3.0±1	<.2	4.0±.4	4.0±.4
30N-V3	.22±.07	.78±.17	.5 ±.1	.24±.06	1.7±.2	26±.2	0.7±.1	2.8±.2	<.3	1.2±.2	<1.6	7.0±1	<.4	8.9±.7	7.5±.6
30-V4	<.1	<.16	<.05	.18±.04	.26±.05	26±.1	<.2	.5±.1	<.2	.4±.1	<1.6	2.2±.9	<.2	3.2±.3	1.7±.3
36-V2	115±.4	2.8±1.0	3.1±.4	<.5	1.3±.4	3.8±1.5	2.5±.6	6.5±.6	<1.3	<1.9	<8	14±5	< 2	91±7	83±3
35-V3	<.15	<.4	.46±.06	.38±.06	<.2	44±3	<.3	1.4±.2	<.3	1.5±.2	<1.6	2.3±1	<.4	19±1	18±1

TABLE 5

MAJOR AND TRACE ELEMENTS CONCENTRATIONS IN AIRBORNE PARTICULATES

μg/m³

Location	Total Volume m³	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn
Section 30 Vent 4	11.81	<225	<37	786	42	3.1	398	<.03	<0.3	<0.2	<0.1	<0.1	<.07	0.6	1.7
Section 36 Vent 2	11.30	< 39	<23	<23	<0.8	<1.2	<0.4	1.6	<0.3	<0.2	<0.1	6.4	<.08	.13	1.0
Section 35 Vent 3	10.19	< 43	<20	139	8.7	<1.3	12	<0.5	<0.3	<0.2	<0.2	<.10	<.09	<.01	0.6
Section 30W Vent 1	9.34	< 47	<32	98	6.3	2.5	33	<.07	<0.3	<0.2	<0.2	<.06	<.09	.08	1.4
Section 30W Vent 3	7.36	< 60	<40	80	4.0	<1.8	32	0.2	<0.4	<0.3	<0.2	6.2	<0.1	.06	2.2

		Ga	As	Se	Br	Rb	Sr	Y	Zr	Nb	Mo	Hg	Pb	U
Section 30 Vent 4	11.81	<.09	<0.1	<.09	.01	<0.1	4.1	<0.2	<0.2	<0.2	<0.2	<0.2	0.7	0.6
Section 36 Vent 2	11.30	<.09	<0.2	<.09	0.9	<0.1	<0.4	<0.2	<0.2	<0.2	<0.2	<0.3	3.3	<0.4
Section 35 Vent 3	10.19	<.10	<.06	<0.1	<.01	<0.1	0.8	<0.2	<0.2	<0.2	<0.3	<0.3	<0.3	<0.5
Section 30W Vent 1	9.34	<0.1	<0.1	<0.1	<.09	<0.1	0.5	<0.2	<0.2	<0.3	<0.3	<0.3	0.6	<0.4
Section 30W Vent 3	7.36	<0.1	<0.2	<0.1	<.01	<0.2	5.4	<0.3	<0.3	<0.4	<0.4	<0.4	<0.5	<0.8

TABLE 6

WATERBORNE PARTICULATE EMISSION RATE

mg/day

Vent	Volume ℓ/min	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn	Fe	Ni	Cu	Zn	Ga	As
30W V1	1.7	760	2900	<61	190	<20	150	880	32	2.7	3.9	10	880	13	7.8	14	<0.2	0.73
30W V3	2.9	8400	27000	710	2300	170	1500	4200	250	21	7.5	46	10000	<1.0	7.5	50	0.91	3.3
30 V4	13	3900	7700	<370	1600	<127	670	4300	120	<9	12	18	5800	<1.9	11	45	<1.9	<3.0
36 V2	0.1	960	2300	<35	<29	<12	120	52	37	6.2	1.9	24	1600	0.49	2.6	19	0.22	0.40
35 V3	~10	19000	43000	<920	7300	490	2400	11000	400	85	20	190	29000	3.7	20	216	<2.2	<5.8

		Se	Br	Rb	Sr	Y	Zr	Nb	Mo	Sb	Ba	Hg	Pb	U
30W V1	1.7	0.64	0.27	0.41	24	<0.5	1.7	<0.5	0.73	<3.4	7.3	<0.5	9.8	9.8
30W V3	2.9	2.1	1.00	7.1	110	2.9	11.7	<1.2	5.0	<6.7	29	<1.7	37	31
30 V4	13	<0.9	3.4	4.9	48.7	<3.7	9.4	<3.7	7.5	<30	41	<3.7	60	32
36 V2	0.1	0.45	0.07	0.19	0.55	0.36	0.94	<0.19	<0.27	< 1.2	2.0	<0.3	13	12
35 V3	~10	<6.6	5.4	<2.9	590	<4.3	20.2	4.3	22	23	33	5.8	274	260

TABLE 7

AIRBORNE PARTICULATE EMISSION RATE

gms/day

Vent	Flow Rate 10^6 ℓ/min	Ca	S	Cl	K	Fe	Cu	Zn	As	Se	Br	Sr	Pb	U	Si	P
30-V4	1.2	688	1400	73	5.4	<0.1	<0.1	2.9	<0.4	<0.2	<0.6	7.1	1.2	1.0	<390	<64
36-V2	2.2	<1.3	< 73	<2.5	<3.8	20	0.4	3.2	<0.6	<0.3	2.9	<1.3	10	<0.1	<124	<73
35-V3	2.0	<47	540	34	<5.1	<0.4	< .04	2.3	<0.2	<0.4	< .04	3.1	<1.2	<1.9	<167	<78
30W-V1	2.7	105	310	20	7.9	<0.3	.03	4.4	<0.3	<0.3	<0.3	1.6	1.9	<1.3	<149	101
30W-V3	2.2	92	230	12	<5.2	18	0.2	6.3	<0.6	<0.3	< .03	16	<1.4	<2.0	<173	115

Vent	Flow Rate 10^6 ℓ/min	Ti	V	Cr	Mn	Ni	Ga	Rb	Y	Zr	Mo
30-V4	1.2	<518	<0.5	<0.3	<0.2	<0.1	<0.2	<0.2	<0.3	<0.3	<0.3
36-V2	2.2	<5.1	<0.8	<0.6	<0.3	<0.3	<0.3	<0.3	<0.6	<0.6	<0.6
35-V3	2.0	<19	<1.1	<0.8	<0.8	<0.3	<0.4	<0.4	<0.8	<0.8	<1.2
30W-V1	2.7	< 0.2	<1.0	< .06	<0.6	<0.3	<0.3	<0.3	<0.6	<0.6	<1.0
30W-V3	2.2	< 0.5	<1.2	<0.3	<0.6	<0.3	<0.3	<0.6	<0.9	<0.9	<1.2

TABLE 8

^{230}Th, ^{226}Ra, AND ^{40}K IN MINE VENT WATER AND AQUEOUS PARTICULATES AT EXHAUST VENTS

pCi/liter †

Location	Date	Sample*	^{232}Th (^{208}Tl)	^{226}Ra (^{214}Bi)	^{40}K
30W Vent 1	4-9-79	Filtrate	<3	<4	318±250**
		Particulate	<2	<3	<75
30 Vent 4	4-6-79	Filtrate	<4	<6.3	<300
		Particulate	<3	<3.	<100
35 Vent 3	4-8-79	Filtrate	<4	<8	<300
		Particulate	<2	9.5**	<85
36 Vent 2	4-7-79	Filtrate	<13	<19	<630
		Particulate	<6	16**	<250
30W Vent 3	4-9-79	Filtrate	<3	<6	<220
		Particulate	<2	4.5**	<60

*Particulate was that material collected on a 0.45μ Millipore filter from 1000 ml of water collected at the vent exhaust.

**Statistically positive result with approximately 100% uncertainty.

†These values can be compared to the MPC in water of 3 x 10^4 pC/ℓ for ^{226}Ra, and 4 x 10^4 for ^{232}Th.

TABLE 9

^{228}Th, ^{226}Ra, and ^{40}K IN AIRBORNE PARTICULATES FROM UNDERGROUND URANIUM MINE VENTS - APRIL 1979

pCi/m^3*

Location	^{228}Th(^{208}Tl)	^{226}Ra(^{214}Bi)	^{40}K
Section 30, Vent 4	<0.27	<1.3	<18
Section 30, Vent 4, #2	<0.04	<0.27	<2.8
Section 30W, Vent 1	<0.10	<0.38	<5.4
Section 30W, Vent 3	<0.03	<0.27	<6.3
Section 36, Vent 2	<0.095	<0.38	<5.0
Section 35, Vent 3	<0.12	<0.41	<5.4

*These values can be compared with the MPC's for insoluble species in air of 2 pCi/m^3 for ^{226}Ra and 1 pCi/m^3 for ^{232}Th.

TASK 3

THORIUM CONTENT OF OVERBURDEN, SUBORE, AND ORE

INTRODUCTION

The Uranium Mill Tailings Radiation Control Act requires information on the extent of thorium mineralization or disequilibrium with respect ot it and its daughter content in overburden, subore, and ore. The data are required to determine if ^{232}Th or its chain members are a significant contributor to the radiological hazard associated with uranium mining. In order to initiate a data base, analysis of thorium and its daughters was completed on selected samples obtained from open-pit mines near Casper, Wyoming, and in the Grants, New Mexico region.

EXPERIMENTAL PROTOCOL

A variety of samples was collected in the New Mexico and Wyoming uranium mining regions for radiological and trace element analysis. Surface samples of ore, subore, overburden, and surrounding soils were obtained, and, in some cases, depth profiles were also obtained. The surface soil samples were 4-cm thick and weighed about 600 grams. Vertical profile samples were collected by digging a trench and then taking successive 5-cm thick samples from the side of the trench to soil depths of 75 cm. Selected samples or composites thereof were analyzed for trace elements using X-ray fluorescence and instrumental neutron activation analysis techniques as discussed in the Appendix. Radionuclide concentrations in uranium ore, subore, and overburden were measured by multidimensional gamma-ray spectrometry and alpha spectrometry. Results of the analyses of these samples and sample descriptors can be found in the tables associated with Task 10 - Soil Sampling, Tables 1, 2, and 5. The summary of these element and radionuclide data is given in Table 1; the arithmetic average of individual analyses of the selected samples is given in Table 2. Instances of major disequilibrium, as noted in Task 10, were excluded from this summary.

DISCUSSION

It is apparent from the data on ^{232}Th-^{228}Th and ^{238}U-^{226}Ra pairs that these two natural chains are in approximate radioactive equilibrium, although as noted in Task 10 certain samples taken from specific sites did evidence significant disequilibrium within the ^{238}U series.

The concentrations of ^{232}Th were essentially uniform in all sample types collected at a given mining region. Concentrations averaged 1.3 pCi/g in samples from Morton Ranch, Wyoming, and 0.5 pCi/g in the Grants, New Mexico region. Uranium-238 concentrations in these same samples, on the other hand, varied from as little as 1 pCi/g in background soil to 190 pCi/g in an ore specimen.

The detailed trace element data of Task 10, Table 5, indicate that a common trace element composition does not occur in these soils, even as a function of depth. Both trace element and radionuclide data suggest that a variety of soils and geological types of rock are in coexistence in the areas studied.

Table 1 also shows the gross thorium concentrations as well as the isotopic thorium compositions (^{232}Th, ^{230}Th, and ^{228}Th) measured by the U. S. Environmental Protection Agency and by Battelle, Pacific Northwest Laboratory. The ^{228}Th data obtained by the U. S. Environmental Protection Agency and Battelle, Pacific Northwest Laboratory, are in good agreement for samples collected in the same general area, but not necessarily the same specific sample. An analysis of sample 70 by the Environmental Protection Agency (^{230}Th--481 pCi/g) seems unreasonable in light of data shown in Task 10 for uranium. To have ^{230}Th at a 480 pCi/g level in this sample would require a tremendous disequilibrium of ^{230}Th. The sample was collected in the environment and should be typical of subore. The data shown in Table 1 indicate that in some areas the overburden material had been contaminated with an ore and subore matrix. This is shown quite graphically by the data from the soil samples analyzed for thorium and its daughters as a function of soil depth. The near-surface samples analyzed for ^{230}Th contained greater concentrations of thorium and uranium species than did the samples from depths within the cores. This is indicative of movement of material to that site from an area of ore and subore. This could easily occur at the 1601 pit site due to the storage of ore, subore, and overburden within the same vicinity.

SUMMARY

Natural ^{232}Th was not found to be present in elevated concentrations in any of the ore, subore, wastes, or soils associated with uranium mining

TABLE 1

THORIUM CONTENT OF OVERBURDEN, SUBORE, AND ORE

Sample	Area[‡]	Th μg/g[+]	^{232}Th[†]	^{230}Th[†]	^{228}Th[†]	^{228}Th[++]	Sample Type
61	M	7.0	1.51	161	2.06	0.86	Overburden
62	M	4.5	0.65	2.4	1.12	0.75	Subore
63	M	14	1.71	1.9	1.85	1.44	Subore
64	M	11	1.14	0.9	1.34	1.00	Subore
65	M	11	1.11	1.3	1.74	1.25	Subore
66	M	9.1	1.58	31.4	1.58	1.03	Subore
67	M	5.8	0.90	18	1.47	1.03	Subore
68	M	9.7	0.95	2.9	1.35	0.94	Subore
69	M	5.7	3.08	23.8	2.15	1.25	Subore
70	M	9.3	3.50	481	1.97	0.64	Subore
71	M	12	1.11	23.2	1.25	1.39	Overburden
72	M	8.2	1.33	3.7	1.33	1.14	Overburden
73	M	11	1.00	3.5	1.31	1.08	Overburden
74	M	4.5	0.73	1.9	0.78	0.67	Overburden
75	M	9.2	1.31	1.4	1.25	1.03	Overburden
76	M	5.6	0.42	1.0	0.57	0.56	Overburden
77	M	4.8	0.59	0.7	0.66	0.86	Overburden
78	M	2.7	0.25	0.3	0.44	0.14	Overburden
79	M	1.2	1.25	3.3	1.94	2.02	Overburden
80	M	7.3	1.40	3.3	1.33	0.80	Overburden
81	M	8.0	0.87	1.7	1.04	1.17	Overburden
82	M	10	0.61	2.7	0.33	1.11	Overburden
83	M	9.3	1.49	5.6	1.58	--	Overburden
84	M	7.1	0.72	7.8	1.61	0.56	Overburden
85	M	9.6	1.12	1.4	1.16	0.86	Overburden
86	M	10	1.44	1.6	1.62	1.06	Overburden
87	M	10	1.46	1.5	1.5	0.88	Overburden
88	M	7.2	1.13	12.9	1.54	1.07	Subore
89	M	7.0	1.47	225	2.30	1.58	Ore
90	PC	3.5	0.46	28.7	0.45	0.39	Subore
91	PC	3.1	0.41	11.6	0.50	0.39	Subore
92	PC	3.5	0.56	6.3	0.56	0.42	Overburden
93	PC	3.2	0.45	9.7	0.62	0.44	Overburden
94	PC	3.5	0.56	17.7	1.29	0.42	Overburden
95	PC	4.0	0.53	2.1	0.71	0.53	Overburden
96	BJ	1.7	0.64	62.6	1.86	0.31	Subore
97	BJ	3.6	0.35	2.0	0.43	0.44	Overburden

[+] Errors in analysis vary from ±5 to ±10%.

[†] E.P.A. data. Errors shown in Table 2, Task 10, of this report.

[++] Battelle data. Errors in analysis to ±25%.

[‡] M = Morton Ranch, Casper, Wyoming; PC = Poison Canyon, Ambrosia Lake, New Mexico; BJ = Barbara J #1, Ambrosia Lake, New Mexico.

operations. Its average concentrations were 1.3 pCi/g in the Morton Ranch, Wyoming area, and 0.5 pCi/g in the Grants, New Mexico region. These concentrations are typical of those found in natural earth crust materials which do not show mineralization of thorium. It seems that these observations are sufficient to establish that the ^{232}Th chain is not likely to be a significant contributor to the radiological hazard associated with uranium mining.

RECOMMENDATIONS

This brief study created a small data base for the investigation of the thorium content in overburden, subore, and ore. However, since samples were analyzed from only two states, it does not represent the entire uranium industry. Samples should be taken in areas containing ore, subore, and overburden at other mining sites within the United States to verify that the conclusions derived from these data are applicable to a broad-range uranium industry. Although it is outside the range of this particular study, the nonuniformity in the ^{238}U/^{226}Ra chain should be investigated. This disequilibrium cannot be explained with the limited data base accumulated here.

TASK 4

ANALYSIS OF POLLUTANTS IN AQUEOUS EFFLUENTS AND WASTES

INTRODUCTION

The analysis of pollutants in aqueous effluents and wastes was initiated to generate an initial data base for the Uranium Mill Tailings Radiation Control Act. The analyses of trace elements and radionuclides were performed on a variety of vent effluent waters from underground mines, from the mine dewatering discharges, from streams receiving the mine discharge, from streams below various seeps extending from open-pit and underground mine discharges, and from seeps resulting from acid and basic leach mill operations. By using a variety of analytical techniques, more than 30 elements were measured in the particulate and soluble fractions of these waters. Thorium-232, ^{226}Ra, ^{222}Rn, and ^{40}K were also measured in selected samples.

EXPERIMENTAL PROTOCOL

Analyses of trace elements and radionuclides were performed on selected water samples from mine drainage (Table 1) in the Ambrosia Lake, New Mexico area and at Morton Ranch, Wyoming; not all samples were analyzed for both. In New Mexico, water was sampled as it was entering treatment ponds after being pumped from active underground mines. One sample from Wyoming was from a shallow well which penetrated an aquifer in the bottom of the inactive 1704 pit. Other Wyoming samples were collected from ponds adjacent to open-pit operations which collected some mine drainage. Water exhausted from underground mines with the ventilation air was also sampled in conjunction with particulate analyses of Task 2. Analyses were conducted on both the particulate and soluble fractions to more closely identify the form of pollutant species. The Wyoming samples and the samples collected from mine vents were filtered in the field and both fractions were transported to the laboratory for analysis. Because pond inlet samples collected in New Mexico were not filtered until after they had been acidified in the field to 0.1 N HNO_3, the soluble fraction of many elements certainly was increased in these samples. Thus, these latter samples are interpreted only with respect to their total elemental concentrations for those elements which are acid soluble.

Filterable species were determined using an X-ray fluorescence technique and soluble elements were measured using a combination of plasma emission spectroscopy and atomic absorption techniques.* Concentrations of particulate species were normalized to the volume of solution from which they were filtered.

DISCUSSION

Elemental concentrations for each fraction collected in Table 2 show that molybdenum, selenium, arsenic, and nickel were predominantly soluble species in almost all samples. Aluminum appeared to be predominantly an insoluble species. The transition metals did not exhibit a consistent behavior, being associated with both high and low particulate fractions in individual samples. Part of this behavior is caused by variation in the total amount of particulates collected with a given sample, which can be inferred from the silicon content in Table 2. The elevated total concentrations of vanadium, titanium, selenium, and molybdenum in the pond inlet samples appear to be related to the total solids content of these samples. When these elements are normalized to the particulate silicon content, these pond inlet ratios are not significantly different from the other samples.

An acid blank was collected by the Environmental Protection Agency with the water samples from New Mexico and sent to the Battelle laboratory. However, this sample may be either sample 26 or 34, and arrived with its label totally blurred; therefore, we were unable to generate data on these two samples or decide how to interpret their analytical results.

In general, the elemental concentrations observed at the open-pit areas of Poison Canyon more closely resembled those encountered around the open-pit operation in Wyoming. Elevated selenium in the soluble form was observed in a seep well in the bottom of the Wyoming open pit, as well as in the small open-pit pond of Poison Canyon. The total concentrations of selenium discharged in drainage water from underground mines often exceeded the drinking water standard of <10 μg/ℓ (Ref. 1). The same level has been recommended as a criterion for livestock water supplies (Ref. 2). The pond in Poison Canyon and some water from Wyoming also exceeded this level. The standard for lead (<50 μg/ℓ) was exceeded only in one sample of vent water. Although cadmium in excess of the 10 μg/ℓ standard was noted in several water samples in Wyoming and in the pond in New Mexico, the reagent and equipment blank from Wyoming contained cadmium, making the results equivocal. The levels of chromium and barium did not exceed the U. S. drinking water standards in any of the samples. Although the concentrations of iron, molybdenum, and aluminum are high, no standards for them have been set at present.

Selenium appears to represent the most serious potential problem of the elements we have measured since in some cases these surface waters may be accessible to livestock. An effect on aquatic species may also be significant if the waters are fed to small streams since the concentrations of iron, zinc, lead, and copper occasionally exceed the suggested criteria for stream concentrations of the State of Colorado (Ref. 3).

The analyses of radionuclides shown in Table 3 were limited to those species which could be determined directly by multiparameter gamma-ray spectroscopy. Of those species measured, only ^{226}Ra and ^{222}Rn were sufficiently concentrated to be detected. The ^{232}Th concentrations were far below the limiting concentrations of 12000 pCi/ℓ and 40,000 pCi/ℓ tabulated in 10 CFR 20 (1978) for soluble and insoluble species in water in unrestricted areas. The soluble ^{226}Ra from underground mines may exceed the NRC limit of 30 pCi/ℓ for public waters; however, since these samples had been acidified prior to filtration, the actual fractionation between soluble and insoluble species is uncertain. The potential of a high soluble radium content has been recognized. In fact, these samples were taken at the mine outlets which are feeding water treatment ponds used, in part, to remove radium. Since the outlet of the treatment process was not sampled, its effectiveness cannot be estimated here. The quantity of radon dissolved in water exhausted from underground mines was an extremely small fraction of the total radon escapement from the vents as shown in Task 2 of this report.

SUMMARY

Molybdenum, selenium, arsenic, and nickel were found in a soluble form. Aluminum was predominantly insoluble. The transition metals did not exhibit consistent behavior. Selenium appeared to represent the most serious potential problem of the elements measured since elevated selenium was found in the soluble fraction. Lead and cadmium concentrations were in general below drinking water standard levels. Chromium and barium did not exceed the U. S. drinking water standards. The analyses of radionuclides indicated that ^{232}Th, ^{226}Ra, ^{222}Rn, and ^{40}K concentrations were far below the standards for particulate and soluble radionuclides in public waters. The quantity of radon dissolved in water exhausting from underground mines was found to be an extremely small fraction of the total radon escapement from the vents.

RECOMMENDATIONS

The data base created in this study represents only two limited areas in the uranium mining industry--the Ambrosia Lake area of New Mexico and the Morton Ranch area in Wyoming. Further studies are required to measure the radioactive and trace element compositions of aqueous effluents and wastes in other areas of the uranium mining industry. In addition, these studies primarily emphasized surface drainages and runoffs; this was not a study of the hydrologic movement of underground trace elements or radionuclides. A study should be completed to encompass the movement of trace elements and radionuclide materials from areas occupied by the uranium mining and milling industry.

TABLE 1

WATER SAMPLE DESCRIPTORS

PNL #	
10	Vent effluent water, Section 30W, Vent 1, New Mexico
11	Vent effluent water, Section 30, Vent 4, New Mexico
12	Vent effluent water, Section 35, Vent 3, New Mexico
13	Vent effluent water, Section 36, Vent 2, New Mexico
14	Vent effluent water, Section 30W, Vent 3, New Mexico
15	Underground mine dewatering discharge, Section 36, New Mexico
16	Underground mine dewatering discharge, Section 35, New Mexico
17	Underground mine dewatering discharge, Section 19, New Mexico
18	Underground mine dewatering discharge, Section 17, New Mexico
19	Underground mine dewatering discharge, Section 30W, New Mexico
20	Underground mine dewatering discharge, Section 30, New Mexico
21	Underground mine dewatering discharge, Section 36, New Mexico
24	San Mateo Creek downstream of mine discharge at Marquez Ranch--acidified before filtering, New Mexico
25	San Mateo Creek 2 km upstream of mine drainage--acidified before filtering, New Mexico
26	Unidentified. Sample label blurred.
27	Morton Ranch W-1, demineralized unfiltered water blank, Wyoming
28	Morton Ranch W-2, demineralized filtered water blank, Wyoming
29	Morton Ranch W-3, seep water in shallow well--1704 pit, filtered, Wyoming
30	Morton Ranch W-4 about 8 km below 1601 pit, Wyoming
31	Morton Ranch W-5, 1704 spoil bank pit, Wyoming
32	Morton Ranch W-6, Box Creek above 1601 pit, below 1704 pit, Wyoming
33	Morton Ranch W-7, Box Creek below 1601 pit drainage, Wyoming
34	Unidentified. Sample label blurred.
35	Poison Canyon, pond water Area 3, New Mexico
36	Poison Canyon, well water Area 2, New Mexico
37	Vent effluent water, Section 30W, Vent 3, New Mexico
38	Vent effluent water, acid blank, New Mexico
39	Blue Jay Mine, standing water, Boulder, Colorado
40	Acid leach mill, north evaporation pond, New Mexico
41	Basic leach mill, seep pond, New Mexico
42	Acid leach mill, seep pond, west side, New Mexico
43	Basic leach mill, seep east side, New Mexico
44	Acid leach mill, acid leach pond, New Mexico
45	Basic leach, input slurry, New Mexico
46	Pond solution, east side, basic leach, New Mexico
47	San Mateo Creek upstream north 2 km from San Mateo mine, unacidified before filtering, New Mexico
48	San Mateo Creek downstream from San Mateo mine at Marquez Ranch, unacidified before filtering, New Mexico
49	Acid leach mill, north side, seep, New Mexico
50	Vent effluent water, Section 30W, Vent 1, resample, New Mexico

TABLE 2. Elemental Composition of Aqueous Mine Effluents (ppm)

AMBROSIA LAKE, NEW MEXICO

Fraction	PNL #	Al*	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn
Particulate	10	310	1,200	<25	78	<8.2	63	360	13	1.1	1.6	4.1
Fraction Particulate		0.53								0.06	0.35	0.05
Particulate	11	210	410	<20	83	<6.8	36	230	6.6	<0.5	0.64	0.96
Fraction Particulate		0.46										0.01
Particulate	12	1,300	3,000	<64	510	34	170	740	28	5.9	1.4	13
Fraction Particulate		0.92								0.40		0.20
Particulate	13	6,700	16,000	<240	<200	<83	860	360	260	43	13	170
Fraction Particulate		1.00										0.34
Particulate	14	2,000	6,400	170	550	40	350	1,000	60	5.1	1.8	11
Fraction Particulate		0.89								0.23		0.03
Particulate	15	37,000	110,000	1,100	830	<120	4,300	580	800	360	<9.6	28
Fraction Particulate		0.93								0.51	<0.44	0.09
Particulate	16	55,000	230,000	2,300	750	<170	8,600	740	1,600	230	<10	37
Fraction Particulate		0.95								0.93	<0.56	0.10
Particulate	17	37,000	160,000	1,900	610	<110	6,300	650	1,000	73	<7.1	23
Fraction Particulate		0.95								0.60	<0.59	0.09
Particulate	18	63,000	220,000	2,300	800	<150	7,800	820	1,500	160	9.7	23
Fraction Particulate		0.94								0.56	0.49	0.06
Particulate	19	37,000	180,000	1,700	1,500	<130	6,300	1,400	1,300	100	<8.3	24
Fraction Particulate		0.90								0.48	<0.43	0.04
Particulate	20	2,500	<3,100	<350	900	<78	1,700	1,300	500	78	<6.3	21
Fraction Particulate		0.61								0.60	<0.44	0.03

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* Particulate aluminum measurements are subject to self-absorption errors in their analysis by X-ray fluorescence of about a factor of two. The tabulated values are for comparison only.

TABLE 2. (contd)

AMBROSIA LAKE, NEW MEXICO (ppm)

Fraction	PNL #	Fe	Co	Ni	Cu	Zn	Ga	Hg	Se	Pb	As	Br
Particulate	10	360	<1.2	5.2	3.2	5.6	<0.09	<0.2	0.30	4.0	0.3	0.11
Fraction Particulate		0.13		0.29	0.51				0.03	0.44	0.03	
Particulate	11	310	<1.1	<0.098	0.64	2.4	<0.07	<0.18	<0.05	3.2	<0.16	0.18
Fraction Particulate		0.12		0.01	0.18				<0.003		<0.03	
Particulate	12	2,000	<2.8	0.26	1.4	15	<0.15	<0.36	0.46	19	<0.39	0.38
Fraction Particulate		0.74		0.03	0.22				0.03	0.61	<0.02	
Particulate	13	11,000	<14	3.4	18	130	1.5	<2.0		92	2.8	<0.5
Fraction Particulate		0.99				0.73				0.60		
Particulate	14	2,500	<3.1	<0.25	1.8	12	0.22	<0.40	0.50	9.0	0.78	0.24
Fraction Particulate		0.55		<0.02	0.47				0.05	0.69	0.08	
Particulate	15	4,500	<13	<1.6	5.1	12	3.5	<3.6	34	12	1.7	1.5
Fraction Particulate		0.38		<0.17	0.32	0.13			0.76		0.16	
Particulate	16	5,200	<14	2.2	4.4	16	5.7	<4.1	48	7.4	1.8	1.3
Fraction Particulate		0.83		0.14	0.29	0.14			0.27	0.45	0.14	
Particulate	17	3,500	<12	<1.4	3.6	9.0	4.4	<3.5	5.3	<37	<1.2	1.2
Fraction Particulate		0.42		<0.09	0.24	0.09			0.08	<0.35	<0.17	
Particulate	18	4,500	<13	<1.6	6.0	12	5.5	<3.9	7.8	<4.1	2.2	<1.0
Fraction Particulate		0.79		<0.10	0.33	0.12			0.14	<0.33	0.27	
Particulate	19	4,100	<13	<1.5	5.4	13	4.2	<3.6	14	5.4	<1.4	1.8
Fraction Particulate		0.76		<0.06	0.26	0.10			0.15	0.43	0.15	
Particulate	20	2,800	<11	2.1	5.9	8.4	3.2	<3.2	7.2	<3.8	2.2	1.5
Fraction Particulate		0.28		0.10	0.26	0.14			0.05	<0.43	0.24	

TABLE 2. (contd)

AMBROSIA LAKE, NEW MEXICO (ppm)

Fraction	PNL #	Rb	Sr	Y	Zr	Nb	Mo	Sb	Ba	U	Be	Cd
Particulate	10	0.21	9.8	<2	5	<3	<3	<15	25	<6		
Fraction Particulate							<0.05		0.27			
Particulate	11	0.26	2.2	<0.2	0.5	<0.2	0.4	<1.6	2.2	1.7		
Fraction Particulate							<0.04		0.15			
Particulate	12	<0.16	41	<0.3	1.4	<0.3	1.5	<1.6	2.3	18		
Fraction Particulate							0.04		0.17			
Particulate	13	13	3.8	2.5	6.5	<1.3	<1.9	<8.0	14	83		
Fraction Particulate							<0.32		0.23			
Particulate	14	1.7	26	0.70	2.8	<0.30	1.2	<1.6	7.0	7.5		
Fraction Particulate							0.01		0.33			
Particulate	15	19	14	5	32	4.4	5.9	<15	100	23		
Fraction Particulate							0.46		0.61			
Particulate	16	37	22	5	68	10	83	<16	170	40		
Fraction Particulate							0.04		0.80			
Particulate	17	26	21	3	48	3.7	27	<16	75	9		
Fraction Particulate							0.03		0.63			
Particulate	18	31	23	8	51	5.7	47	<16	120	46		
Fraction Particulate							0.05		0.71			
Particulate	19	23	31	4.0	33	5.4	55	<16	120	26		
Fraction Particulate							0.04		0.75			
Particulate	20	14	31	4.8	33	4.0	54	<16	50	54		
Fraction Particulate							0.04		0.62			

TABLE 2. (contd)

MORTON RANCH, WYOMING (ppm)

Fraction	PNL #	Al*	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn
Particulate	27											
Fraction Particulate												
Particulate	28	260	<71	<37	<27	17	<2.8	6.3	<0.67	<0.45	<0.38	<0.26
Fraction Particulate												
Particulate	29	12,000	37,000	490	<100	<41	960	860	170	63	8.5	27
Fraction Particulate		1.00								0.89		0.26
Particulate	30	2,200	5,900	130	63	35	190	250	32	20	<0.85	7.6
Fraction Particulate		0.96								0.77		0.05
Particulate	31	8,900	26,000	460	86	<26	680	13,000	150	9.6	4.1	34
Fraction Particulate		1.00								0.66		0.79
Particulate	32	590	1,000	53	19	18	34	130	6.2	<0.71	<0.53	13
Fraction Particulate		0.89								<0.07		0.12
Particulate	33	1,200	3,000	92	41	25	75	820	14	1.1	<0.66	20
Fraction Particulate		0.94								0.14		0.48

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* Particulate aluminum measurements are subject to self-absorption errors in their analysis by X-ray fluorescence of about a factor of two. The tabulated values are for comparison only.

TABLE 2. (contd)

MORTON RANCH, WYOMING (ppm)

Fraction	PML #	Fe	Co	Ni	Cu	Zn	Ga	Hg	Se	Pb	As	Br
Particulate Fraction	27											
Particulate												
Particulate Fraction	28	4.5	<0.22	<0.13	0.88	0.76	<0.12	<0.44	<0.13	<0.51	<0.17	<0.13
Particulate					0.11					<0.15		
Particulate Fraction	29	2,200	<3.9	2.6	4.0	13	0.86	<0.77	41	4.6	<0.17	<0.19
Particulate		0.87			0.44				0.11	0.60		
Particulate Fraction	30	630	<2.1	<0.45	1.8	6.3	<0.16	<0.52	<0.13	1.0	0.31	<0.15
Particulate		0.56		0.10					0.03			
Particulate Fraction	31	500	<3.4	1.2	3.5	7.7	0.78	0.75	0.63	1.4	0.48	0.43
Particulate		0.90		0.2					0.008			
Particulate Fraction	32	140	<0.99	0.24	1.6	1.2	<0.12	<0.47	<0.14	<0.56	0.21	<0.14
Particulate		0.24										
Particulate Fraction	33	300	<1.4	<0.34	1.6	1.5	0.2	<0.50	<0.19	<0.57	<0.19	0.17
Particulate		0.43			0.24							

TABLE 2. (contd)

MORTON RANCH, WYOMING (ppm)

Fraction	PNL #	Rb	Sr	Y	Zr	Nb	Mo	Sb	Ba	U	Be	Cd
Particulate	27											
Fraction Particulate												
Particulate	28	<0.21	<1.7	<0.4	<0.5	<0.5	<0.5	<2.7	<3	<1.0		
Fraction Particulate									<0.75			
Particulate	29	4.3	7.3	1.4	9.8	0.6	<0.8	<2.7	22	17		
Fraction Particulate							<0.05		0.26			
Particulate	30	1.1	2.9	<0.4	1.2	<0.5	<0.5	<2.9	<3	<1.1		
Fraction Particulate							<0.02		<0.06			
Particulate	31	4.5	9.0	<0.6	6.9	<0.7	<0.7	<3.1	16	<1.7		
Fraction Particulate							<0.15					
Particulate	32	<0.23	<1.8	<0.4	<0.4	<0.5	<0.5	<2.9	<4	<1.0		
Fraction Particulate							<0.03		<0.27			
Particulate	33	0.35	<1.8	<0.4	0.6	<0.5	<0.5	<2.7	4	<1.0		
Fraction Particulate							<0.03		<0.04			

TABLE 2. (contd)

POISON CANYON, NEW MEXICO (ppm)

Fraction	PNL #	Al*	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn
Particulate	35	840	1,500	110	72	<16	89	380	11	<0.93	1.1	21
Fraction Particulate		0.94								0.04		0.48
Particulate	36	1,200	3,000	120	<57	24	170	800	32	2.3	<0.83	4.9
Fraction Particulate		0.96								0.22		0.77
Particulate	39											
Fraction Particulate												

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* Particulate aluminum measurements are subject to self-absorption errors in their analysis by X-ray fluorescence of about a factor of two. The tabulated values are for comparison only.

TABLE 2. (contd)

POISON CANYON, NEW MEXICO (ppm)

Fraction	PNL #	Fe	Co	Ni	Cu	Zn	Ga	Hg	Se	Pb	As	Br
Particulate	35	99	<0.88	0.63	2.5	4.0	<0.15	<0.54	0.47	1.8	<0.24	0.28
Fraction Particulate		0.24			0.22				0.003		0.02	
Particulate	36	380	<1.6	0.30	2.0	8.1	<0.20	<0.61	<0.16	12	<0.45	0.23
Fraction Particulate		0.60			0.29				<0.02			
Particulate	39											
Fraction Particulate												

TABLE 2. (contd)

POISON CANYON, NEW MEXICO (ppm)

Fraction	PNL #	Rb	Sr	Y	Zr	Nb	Mo	Sb	Ba	U	Be	Cd
Particulate	35	<0.26	<1.9	<0.4	0.9	<0.6	<0.9	<2.9	<4	22		
Fraction Particulate							<0.007		<0.05			
Particulate	36	0.88	<2.0	<0.5	0.8	<0.6	<0.6	<3.0	<4	<1.2		
Fraction Particulate							<0.03		<0.03			
Particulate	39											
Fraction Particulate												

TABLE 3

^{232}Th, ^{226}Ra, ^{222}Rn and ^{40}K IN POND WATERS REMOVED FROM UNDERGROUND AND OPEN PIT MINES

(pCi/ℓ)

PNL #	Location	Sample	^{232}Th	^{226}Ra	^{222}Rn	^{40}K
AMBROSIA LAKE, N. M.						
15	Section 36 Pond Inlet	H_2O	<3.1	570	830	<80
		Particulate	<1.8	110		<40
16	Section 35 Pond Inlet	H_2O	<3.1	430	670	<90
		Particulate	<1.9	120		<40
17	Section 19 Pond Inlet	H_2O	<3.1	330	250	<120
		Particulate	<2.6	10		<30
18	Section 17 Pond Inlet	H_2O	<1.3	150	310	<90
		Particulate	<2.5	30		<45
19	Section 30W Pond Inlet	H_2O	<5.0	330	260	<120
		Particulate	<2.1	40		<60
20	Section 30 Pond Inlet	H_2O	<3.6	220	220	<120
		Particulate	<1.8	20		<30
POISON CANYON, N. M.						
35	Area #3 Pond	H_2O	<6.6	<9	---	<120
36	Area #2 Well	H_2O	<5.0	17	---	<110
MORTON RANCH, WY						
29	W-3 Well	H_2O	<4.1	17		
		Particulate	<1.2	<9	---	<145

TASK 5

TRACE ELEMENTS AND RADIONUCLIDES IN SURFACE RUN-OFF FROM ORE, SUBORE, AND OVERBURDEN PILES

INTRODUCTION

Studies of the trace elements in radionuclides in surface run-off from ore, subore, and overburden piles are required by the Uranium Mill Tailings Radiation Control Act. This run-off, however, requires a significant input or precipitation during the experimental time frame. In this study, the short duration of experimental field work necessitated a change in the experimental approach with respect to surface run-off conditions. Although the task was designed to investigate the waterborne transport of trace elements and radionuclides from aboveground mineral storage piles, no significant precipitation fell during the experimental period. Since no precipitation fell, a decision was made in the field to collect soil samples representing the movement of materials from the ore, subore, and overburden piles toward the streams at specific uranium mining and ore milling sites.

EXPERIMENTAL PROTOCOL

The collection of run-off water from inactive mine sites requires conditions of contemporary precipitation at the site. Since the areas being sampled are semidesert in nature, the probability of obtaining these samples of opportunity was low. At the guidance of the Environmental Protection Agency staff, the sampling program emphasized the collection of soil samples in well-defined run-off gullies originating at surface stockpiles of minerals from the mines. Where these drainage systems intersected flowing water, upstream and downstream samples were collected. Most of the samples consisted of the top 5 cm of soil in the bottom of the drainage channel. A second 5-cm core was taken at selected sites in New Mexico. At the Wyoming sites, three core profiles were collected for one site. Samples of the source material were collected at the Wyoming sites and one of the two New Mexico drainage systems investigated. One system in Poison Canyon, New Mexico, was adjacent to several small open-pit operations as well as an underground mine site. For this system, no single source could be defined for the run-off constituents.

Selected samples were taken to the laboratory and analyzed using multidimensional gamma-ray spectroscopy to measure the ^{214}Bi (from ^{226}Ra) and ^{208}Tl (from ^{232}Th). Potassium-40 was determined both by radiochemical and chemical potassium analyses. A number of soil and water samples were also analyzed by the Environmental Protection Agency laboratory for ^{226}Ra, $^{238-234}$U, and $^{232-230}$Th. A broad spectrum of elements was measured using X-ray fluorescence methods, plasma emission spectroscopy, or atomic absorption techniques.

Table 1 gives a list of sample descriptors which identify samples by number and gives the location of soil samples taken in the water drainage areas of the various mines.

TABLE 1

SAMPLE DESCRIPTORS

Correlated to Their PNL and EPA Identification Numbers

PNL #	EPA #	Area	Descriptor
61	203741	Morton Ranch	Soil profile, composite 41 m, 370 m, and top alluvium at 1601 pit
62	203742	Morton Ranch	Top alluvium, profile, #3 1601 pit
63	203743	Morton Ranch	Top alluvium, profile, #6 1601 pit
64	203744	Morton Ranch	Top alluvium, profile, #12 1601 pit
65	203745	Morton Ranch	Top alluvium, profile, #15 1601 pit
66	203746	Morton Ranch	Alluvial fan, profile, #1 1601 pit
67	203747	Morton Ranch	Alluvial fan, profile, #3 1601 pit
68	203748	Morton Ranch	Alluvial fan, profile, #6 1601 pit
69	203749	Morton Ranch	Alluvial fan, profile, #12 1601 pit
70	203750	Morton Ranch	Alluvial fan, profile, #13 1601 pit
71	203751	Morton Ranch	Erosional drainage, 180 m from 1601 pit
72	203752	Morton Ranch	Erosional drainage, 370 m from 1601 pit
73	203753	Morton Ranch	Erosional drainage, 570 m from 1601 pit
74	203754	Morton Ranch	Erosional drainage, 1200 m from 1601 pit, at gate
75	203755	Morton Ranch	South Box Creek sediment, 310 m downstream of 1704 pit
76	203756	Morton Ranch	South Box Creek sediment, SWS-4 at lease boundary
77	203757	Morton Ranch	Box Creek sediment, SWS-6, downstream from N-S Box Creek Junction
78	203758	Morton Ranch	South Box Creek sediment, 90 m above $BaCl_2$ outlet
79	203759	Morton Ranch	South Box Creek sediment, above 1601 pit pond area

TABLE 1 - SAMPLE DESCRIPTORS (continued)

PNL #	EPA #	Area	Descriptor
80	203760	Morton Ranch	Top soil piles 1 & 2, composite 1601
81	203761	Morton Ranch	Soil composite, NE 148A Δ=4
82	203762	Morton Ranch	Soil composite, NE 148A Δ=8
83	203771	Morton Ranch	Bottom alluvium, profile, #1 1704 pit
84	203772	Morton Ranch	Bottom alluvium, profile, #3 1704 pit
85	203773	Morton Ranch	Bottom alluvium, profile, #6 1704 pit
86	203774	Morton Ranch	Bottom alluvium, profile, #12 1704 pit
87	203775	Morton Ranch	Bottom alluvium, profile, #15 1704 pit
88	203777	Morton Ranch	Spoil pile #3, subore
89	203776	Morton Ranch	Ore, composite of #1, 2, 3, & 4 piles
90	203763	Poison Canyon	Area #1, bench
91	203764	Poison Canyon	Area #1, pit floor
92	203765	Poison Canyon	Area #1, terrace
93	203766	Poison Canyon	Area #1, waste pile #1
94	203767	Poison Canyon	Area #1, waste pile #2
95	203768	Poison Canyon	Area #1, background soil
96	203769	Barbara J #1	Waste pile composite
97	203770	Barbara J #1	Background soil
98	NA*	San Mateo	Waste pile composite soil
99	NA	San Mateo	Waste pile composite rocks
100	NA	San Mateo	Waste drainage stream bed soil
101	NA	San Mateo	Waste drainage stream bed, 60 m downstream
102	NA	San Mateo	Background soil, 60 m up side gully
103	NA	San Mateo	Main gully soil, 200-300 m downstream
104	NA	San Mateo	Main gully soil, 400-500 m downstream
105	NA	San Mateo	Side gully soil, gully near heap leach
106	NA	San Mateo	Heap leach soil composite
107	NA	San Mateo	Heap leach rock composite
108	NA	San Mateo	Mud from San Mateo Creek below mine
109	NA	San Mateo	Mud from San Mateo Creek above mine
110	NA	Poison Canyon	Mine drainage sample 5, inside gully above mine drainage
111	NA	Poison Canyon	Mine drainage sample 4, further downstream (C)
112	NA	Poison Canyon	Mine drainage sample 3, further downstream (B)
113	NA	Poison Canyon	Mine drainage sample 2, downstream from mine (A)
114	NA	Poison Canyon	Mine drainage sample 1, 200 m upstream from mine

*NA - Not applicable. EPA did not assign numbers to these samples.

DISCUSSION

A summary of the radiochemical analyses of soil and water samples is shown in Tables 2 and 3, respectively. The chemical analyses of soils and water samples and waterborne particulates are shown in Tables 4 to 6, respectively. Since much of the data interpretation is site specific, the results for each area will be discussed individually.

A. New Mexico Abandoned Mines

Two mine drainage sites in the Grants, New Mexico area were selected for study by Environmental Protection Agency (EPA) personnel--Poison Canyon and San Mateo.

The POISON CANYON mine drainage system (Figure 1) was a dry creek bed. The course of this creek passed an abandoned underground mine site from which it could receive run-off water. It then passed through a dirt roadway and followed a course adjacent to some small open pit mines. After a distance of several hundred meters, it joined a second branch drainage which originated adjacent to a waste pile from one of the open-pit mines. Samples were collected along this waterway starting with a background sample upstream of the underground mine about 200 meters from the road. The first downstream sample was collected about 130 meters downstream from the roadway. This was upstream of run-off sources originating in the open-pit mines. The remaining samples were collected along the drainage way below and in the vicinity of contamination sources from the inactive open-pit operations (see site maps, Task 8, Figures 2, 3, and 4). Soil samples 90 to 95 and 110 to 115, and water samples 35 and 36 were collected at these sites.

The ^{232}Th levels in all soil samples at this site were essentially constant and were the lowest encountered at any of the sites. The ^{226}Ra levels below the underground mine are not significantly different than those above the mine. The sample taken in the branch gully 23 meters below the small waste pile was about 31-fold higher than the background level, indicating leaching of ^{226}Ra from the waste. Contribution of this source to the main drainage was evidenced by elevated levels, approximating twice background, that were detected downstream of its confluence. Uranium-238 concentrations were less than 2 pCi/g in all samples, approximately the same as the background soil level measured at an adjacent area (see Task 10).

TABLE 2. RADIONUCLIDES IN SOIL AND DRAINAGES AROUND URANIUM MINES

(April/May 1979)

pCi/gm

PNL #	Location, Mine, Sample Type	^{238}U**	^{232}Th(^{208}Tl)*	^{230}Th	^{226}Ra(^{214}Bi)	^{40}K**
	MORTON RANCH, WYOMING					
61	Composite, 135, 370 m, top alluvium (near 1601 pit)	189.0	1.03	161.0	77	19
62	Top alluvium #3	1.6	0.74	2.4	1.89	21
63	Top alluvium #6	2.1	1.43	1.9	1.44	15
64	Top alluvium #12	1.3	1.05	0.9	1.04	15
65	Top alluvium #15	1.4	1.23	1.3	1.13	15
66	Top alluvial fan #1	11.0	1.01	31.4	30.0	17
67	Top alluvial fan #3	5.4	1.03	18.0	11.0	20
68	Top alluvial fan #6	1.9	0.93	2.9	3.2	18
69	Top alluvial fan #12	11.0	1.25	23.8	229.0	18
70	Top alluvial fan #15	5.7	2.00	481.0	508.0	19
71	180 m from 1601 erosion channel	7.2	1.38	23.2	38.0	14
72	370 m from 1601 erosion channel	1.9	1.13	3.7	4.0	17
73	579 m from 1601 erosion channel	1.8	1.06	3.5	4.5	14
74	1200 m from 1601 erosion channel	1.6	0.65	1.9	1.9	21
75	Creek sediment, 310 m downstream from 1704 pit	1.0	1.00	1.4	1.08	18
76	Creek sediment, SWS(4) at LEASE boundary near 1601	1.5	0.54	1.0	1.00	18
77	Creek sediment, SWS(6)-N/S Box Creek	0.9	0.85	0.7	1.08	23
78	Creek sediment, 90 m above $BaCL_2$ outlet	0.4	0.14	0.3	0.32	17
79	Creek sediment, W-6 drainage above 1601	7.5	2.0	3.3	6.5	9
80	Top soil composite piles 1 and 2	1.5	0.79	3.3	2.7	18
81	Composite soil - Delta = 4	1.6	1.15	1.7	1.8	17
82	Composite soil - Delta = 8	1.6	1.11	2.7	3.4	17
83	Bottom alluvium #1 (1704 pit)	3.3	1.14	5.6	8.9	14
84	Bottom alluvium #3 (1704 pit)	2.7	0.86	7.8	15.0	18
85	Bottom alluvium #6 (1704 pit)	2.7	0.9	1.4	1.4	14
86	Bottom alluvium #12 (1704 pit)	2.0	1.05	1.6	1.4	16
87	Bottom alluvium #15 (1704 pit)	3.5	0.9	1.5	1.5	17

TABLE 2 (continued)

PNL #	Location, Mine, Sample Type	^{238}U**	^{232}Th(^{208}Tl)*	^{230}Th	^{226}Ra(^{214}Bi)	^{40}K**
88	Soil pile #3 subore	23.7	1.07	13.0	23.0	16
89	Ore composite, piles 1, 2, 3 and 4	192.0	1.58	225.0	180.0	1
SAN MATEO - NEW MEXICO						
98	Waste pile composite soil	63.0	0.86		117.0	14
100	Waste drainage stream bed	14.0	0.64		55.0	14
101	Waste drainage stream bed	18.0	0.66		36.0	--
102	Stream bed soil - background	<0.7	0.55		0.77	12
103	Waste drainage stream bed	<1.3	0.43		1.6	12
104	Waste drainage stream bed	<2.0	0.54		0.77	11.7
105	Waste drainage stream bed	<1.7	0.80		1.2	15
106	Heap leach soil composite		0.94		127.0	15
108	Mud from San Mateo Creek below mine	<1.7	0.53		8.1	15
109	Mud from San Mateo Creek above mine	<1.7	0.39		0.38	15
POISON CANYON MINE DRAINAGE - NEW MEXICO						
110	Secondary gully 23 m below waste pile	<1.7	0.29		36.0	6.8
111	Main channel 67 m below secondary gully intersection	<2.0	0.28		2.1	11.7
112	Main channel 60 m above secondary gully intersection	<2.0	0.35		0.90	9.9
113	Main channel 128 m downstream from road	<1.7	0.36		0.99	11.3
114	Main channel above underground mine (background)	<1.7	0.26		1.17	11.7

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* ^{232}Th = ^{208}Tl/.36

** From chemical analysis (or EPA radiochemical analysis where available)

TABLE 3. RADIONUCLIDE CONCENTRATIONS IN DRAINAGE WATERS FROM URANIUM MINES

				pCi/liter				
PNL #	Location+	Date	Sample*	^{232}Th	^{226}Ra	^{234}U	^{238}U	^{230}Th
47	SM Creek, 2000 m upstream of mine drainage	5-3-79	H_2O	<3.1	<7.2			
			Particulate	<3	<8.1			
48	SM Creek, downstream of mine drainage	5-3-79	H_2O	<2.5	12±5			
			Particulate	<1.9	<2.2			
27	M, deionized water unfiltered, blank	4-23-79	H_2O	<0.02	<0.08	<0.07	0.12±0.04	0.04±0.02
28	M, deionized water filtered, blank	4-23-79	H_2O	<0.02	0.14±0.08	<0.04	<0.04	0.03±0.02
			Particulate	0.06±0.03	<1.1	0.05±0.02	.018±.016	0.07±0.03
31	M, 1704 pit area seep pool from spoil bank	4-23-79	H_2O	0.03±0.02	4.2±0.4	246±52	287±52	0.08±0.04
			Particulate	0.09±0.03	<1.6	0.8±0.1	0.9±0.1	0.75±0.09
32	M, Box Creek above 1601 pit	4-23-79	H_2O	<0.02	0.60±0.14	32.8±2.9	34.2±3.1	0.06±0.03
			Particulate	0.01±0.01	<1.6	0.05±0.03	0.05±0.03	0.06±0.03
33	M, Box Creek below 1601 pit	4-23-79	H_2O	<0.02	0.55±0.14	37.3±3.4	38.7±3.6	0.03±0.02
			Particulate	<1.1	<1.4	0.71±0.11	0.24±0.06	---
30	M. Box Creek about 8 km below 1601 pit drainage	4-23-79	H_2O	<0.02	0.13±0.08	12.3±1.1	10.9±1.0	0.06±0.02
			Particulate	0.007±0.008	<1.4	0.08±0.03	0.05±0.02	0.05±0.02
35	P, Pond - Area 3	4-21-79	H_2O	<0.2	3.3±0.32	1270±171	1350±182	6.8±0.3
			Particulate	0.28±0.017	1.2	8.7±1.0	9.4±1.1	0.25±0.06
36	P, Well pond - Area 2	4-24-79	H_2O	<0.2	3.5±0.033	252±43	269±46	0.05±0.03
			Particulate	0.018±0.016	1.2	0.40±0.08	0.34±0.06	0.25±0.06

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* Particulate is that material filtered from 1000 ml of water by a 0.45 μ Millipore filter.
+ SM = San Mateo, Grants, New Mexico; M = Morton Ranch, Douglas, Wyoming; P = Poison Canyon, Grants, New Mexico.

TABLE 4

ELEMENTAL CONCENTRATIONS IN SOIL SAMPLES FROM ABANDONED MINE DRAINAGE AREAS

(μg/gm soil unless indicated)

PNL #	P (%)	S (%)	Cl (%)	K (%)	Ca (%)	Ti	V	Cr	Mn	Fe (%)
MORTON RANCH, WYOMING										
61	<0.6	<0.19	<0.11	2.4±.1	0.96±.05	1800±100	110±30	34±12	205±17	1.09±.05
62	<0.7	<0.20	<0.09	2.6±.1	0.66±.04	1500±100	<50	37±12	120±12	0.91±.05
63	<0.7	<0.20	<0.10	1.9±.1	0.53±.03	3700±100	150±40	52±16	59±12	2.37±.12
64	<0.6	<0.19	<0.10	1.9±.1	0.47±.03	3100±200	130±30	<29	86±12	1.96±.10
65	<0.6	<0.18	<0.09	1.9±.1	0.43±.03	3100±200	70±30	30±14	57±11	1.66±.08
66	<0.7	<0.19	<0.09	2.1±.1	0.69±.04	1700±100	90±30	42±12	130±13	1.05±.05
67	<0.7	<0.20	<0.09	2.5±.1	0.56±.04	1300±100	<50	42±12	94±11	0.87±.04
68	<0.6	<0.19	<0.10	2.2±.1	0.74±.04	1800±100	60±30	25±13	130±13	1.24±.06
69	<0.7	<0.19	<0.10	2.3±.1	1.04±.06	1500±100	120±30	28±12	190±15	0.96±.05
70	<0.7	<0.21	<0.10	2.4±.1	0.62±.04	1100±100	90±30	29±11	72±10	0.52±.03
71	<0.6	<0.20	<0.09	1.7±.1	0.59±.04	3300±200	160±40	37±15	250±20	2.28±.11
72	<0.7	<0.22	<0.10	2.1±.1	0.47±.03	2500±100	70±30	52±13	200±17	1.24±.06
73	<0.7	<0.20	<0.10	1.7±.1	1.15±.06	3000±200	100±30	44±15	190±17	2.32±.12
74	<0.7	<0.20	<0.10	2.6±.1	0.65±.04	1600±100	<50	37±12	140±13	1.16±.06
75	<0.7	<0.24	<0.10	2.3±.1	0.30±.02	810±60	<42	31±11	114±11	0.46±.02
76	<0.7	<0.20	<0.09	2.3±.1	0.34±.03	1400±100	<51	31±11	100±11	0.76±.04
77	<0.7	<0.22	<0.10	2.8±.2	0.69±.04	1400±100	<50	23±11	107±12	0.88±.04
78	<0.7	<0.20	<0.10	2.1±.1	0.28±.02	780±60	<39	<18	70±9	0.39±.02
79	<0.5	0.31±.09	<0.08	1.1±.1	1.82±.10	2500±100	90±30	71±14	3390±170	2.55±.13
80	<0.7	<0.21	<0.10	2.2±.1	0.49±.03	2300±100	60±30	46±13	190±20	1.34±.07
81	<0.7	<0.20	<0.09	2.1±.1	0.47±.03	2100±100	100±30	43±13	180±20	1.19±.06
82	<0.7	0.21±.10	<0.09	2.1±.1	0.46±.03	2100±100	70±30	<24	180±20	1.15±.06
83	<0.6	<0.17	<0.09	1.8±.1	0.47±.03	2800±200	130±30	42±13	120±10	1.66±.08
84	<0.6	0.20±.09	<0.09	2.2±.1	0.52±.03	1600±100	70±30	<23	110±10	0.94±.05
85	<0.6	<0.19	<0.09	1.7±.1	0.55±.03	2900±200	130±30	45±13	210±20	1.82±.09
86	<0.7	<0.20	<0.10	2.0±.1	0.52±.03	3100±200	90±30	63±15	270±20	2.24±.11
87	<0.7	<0.20	<0.10	2.1±.1	0.51±.03	3000±200	70±30	51±15	350±20	2.09±.10
88	<0.7	0.25±.11	<0.11	2.3±.1	0.66±.04	2900±200	<100	<36	140±10	1.16±.06
89	<0.7	<0.21	<0.10	2.3±.1	0.62±.04	1500±100	200±30	<27	180±20	1.05±.05

TABLE 4 (continued)

PNL #	P (%)	S (%)	Cl (%)	K (%)	Ca (%)	Ti	V	Cr	Mn	Fe (%)
POISON CANYON, NEW MEXICO										
90	1.0±.4	0.30±.12	<0.09	1.1±.1	17.6±.9	2100±100	80±40	<30	310±20	0.79±.04
91	<0.9	<0.23	<0.09	1.1±.1	19.6±1.0	2100±100	<70	<27	340±30	0.70±.04
92	0.8±.4	0.24±.12	<0.09	1.4±.1	13.2±.7	2300±100	<60	<27	280±20	0.87±.04
93	<0.8	0.21±.10	<0.09	1.4±.1	14.5±.7	2200±100	<70	<28	260±20	0.75±.04
94	<0.8	<0.21	<0.09	1.6±.1	10.3±.5	2100±100	<60	<26	220±20	1.00±.05
95	<0.7	<0.21	<0.10	1.8±.1	2.4±.1	1800±100	<50	<23	200±20	0.89±.04
110	<0.8	<0.21	<0.09	1.2±.1	8.7±.44	1195±100	<61	<25	264±20	0.57±.03
111	<0.6	<0.17	<0.08	1.4±.1	2.6±.14	988±100	<44	<16	190±15	0.55±.03
112	<0.6	<0.17	<0.08	1.4±.1	2.0±.11	1247±100	<44	<19	191±15	0.66±.03
113	<0.7	<0.19	<0.09	1.2±.1	1.7±.09	1168±100	<44	<16	167±13	0.50±.03
114	<0.7	<0.20	<0.08	1.4±.1	3.4±.17	903±100	<46	<19	244±17	0.44±.02
BARBARA J										
96	1.2±.3	0.29±.08	<0.06	.53±.04	24.2±1.2	1900±100	180±50	<43	750±50	0.72±.04
97	<0.7	<0.21	<0.10	1.6±.1	0.90±.05	1600±100	<50	<20	190±20	0.76±.04
SAN MATEO, NEW MEXICO										
98	<0.5	0.21±.09	<0.08	2.9±.1	2.9±.2	2200±100	213±30	23±10	300±19	1.4±.07
102	<0.6	<0.17	<0.08	1.6±.1	1.6±0.1	1900±100	<42	26±10	251±17	1.9±.1
100	<0.8	<0.24	<0.10	1.7±.1	1.4±.07	2013±100	78±30	<23	176±15	0.9±.05
101	<0.6	<0.17	<0.08	1.8±.1	1.6±.08	2018±100	114±28	<23	179±15	1.1±.05
103	<0.8	<0.22	<0.10	1.5±.1	1.0±.06	1723±100	<50	<23	191±15	1.3±.06
106										
105	<0.7	<0.19	<0.09	1.8±.1	1.1±.06	2111±100	<52	<23	186±15	1.2±.06
108	<0.7	<0.22	<0.10	1.9±.1	0.70±.04	1800±100	55±20	<22	157±14	0.93±.05
109	<0.7	<0.21	<0.09	1.8±.1	0.68±.04	1829±100	<51	<24	152±14	0.85±.04
104	<0.6	<0.16	<0.08	1.4±.1	0.52±.03	1254±100	<42	27±9	146±13	0.79±.04

TABLE 4 (continued)

BNW #	Ni	Cu	Zn	Ga	As	Se	Br	Rb	Sr	Y	Zr
61	19±2	10±2	29±2	12±1	7.5±1.2	17±1	<1	85±5	95±7	17±2	140±10
62	19±2	8±2	24±2	10±1	5.3±1.0	1.2±.5	<1	100±5	97±7	10±1	84±6
63	36±6	29±3	90±5	18±2	9.1±1.3	<1	<1	111±6	115±8	41±3	250±20
64	32±5	16±2	70±4	16±2	7.5±1.2	1.9±.6	<1	100±5	104±7	24±2	240±20
65	26±3	15±2	58±4	12±1	8.5±1.3	<1	<1	86±5	94±7	22±2	280±20
66	14±2	8±2	26±2	11±1	4.6±1.0	2.7±.6	<1	81±4	94±7	12±1	150±10
67	20±3	11±2	23±2	12±1	3.3±1.0	1.1±.5	1.1±.6	89±5	94±7	9±1	95±7
68	18±2	9±2	29±2	14±1	5.2±1.1	<1	<1	92±5	99±7	11±1	108±8
69	16±3	5±2	22±2	10±1	4.7±1.0	1.3±.5	2.4±.6	86±5	95±7	27±2	130±10
70	8±2	7±1	13±1	9±1	4.9±1.0	<1	<1	89±5	88±6	7±1	101±7
71	23±3	17±2	85±5	17±2	11±1	2.5±.6	1.4±.6	102±5	101±7	20±2	210±10
72	17±2	12±2	36±3	8±1	6.8±1.0	<1	2.1±.5	85±4	90±6	15±1	240±20
73	28±5	21±2	58±4	14±1	8.0±1.1	<1	4.3±.7	91±5	105±7	18±2	250±20
74	14±2	11±2	27±2	10±1	4.2±1.0	<1	1.4±.6	98±5	111±8	10±1	97±7
75	18±2	8±1	10±1	7±1	2.9±.8	<1	<1	88±5	77±5	8±1	60±4
76	11±3	7±1	19±2	9±1	<1.7	<1	1.3±.5	88±5	87±6	9±1	85±6
77	15±3	7±2	22±2	11±1	3.4±.9	<1	1.2±.5	103±5	112±8	9±1	87±6
78	13±2	7±1	9±1	6±1	<1.6	<1	<1	76±4	81±6	7±1	67±5
79	26±5	19±2	81±5	15±2	10±1	7±1	31±2	85±5	197±14	19±2	170±11
80	21±4	13±2	37±3	11±1	3.2±1.0	<1	1.2±.5	98±5	89±6	17±1	190±14
81	14±2	8±2	33±2	9±1	3.9±1.0	<1	<1	87±5	90±6	14±1	200±14
82	15±4	12±2	32±2	9±1	5.6±1.0	<1	<1	92±5	90±6	14±1	210±15
83	19±4	11±2	45±3	14±1	5.6±1.1	1.3±.6	<1	94±5	103±7	19±2	230±17
84	16±3	9±2	23±2	10±1	3.7±1.0	1.1±.5	<1	89±5	93±7	10±1	115±8
85	16±3	17±2	60±4	15±1	6.2±1.1	1.4±.5	2.2±.5	94±5	105±7	20±2	270±20
86	24±5	16±2	58±4	12±1	8.8±1.1	1.1±.5	2.9±.6	102±5	96±7	19±2	230±20
87	24±5	19±2	67±4	13±1	5.7±1.0	1.1±.5	4.2±.6	102±5	102±7	21±2	260±20
88	18±4	9±2	25±2	11±1	<1.8	2.1±.6	<1	75±4	128±9	14±1	150±10
89	17±4	9±2	25±2	11±1	5.4±1.0	28±2	<1	69±4	94±7	17±2	116±8

TABLE 4 (continued)

BNW #	Ni	Cu	Zn	Ga	As	Se	Br	Rb	Sr	Y	Zr
POISON CANYON, NEW MEXICO											
90	9±4	11±2	21±2	7±1	7.0±1.1	2.7±.6	<1	45±2	127±9	12±1	213±15
91	11±4	11±2	18±2	5±1	5.4±1.1	<1	<1	41±2	111±8	10±1	143±10
92	12±4	10±2	24±2	8±1	4.7±1.0	<1	2.0±.6	53±3	98±7	9±1	214±15
93	9±4	11±2	23±2	7±1	7.8±1.1	<1	<1	49±3	99±7	9±1	187±13
94	9±4	13±2	25±2	8±1	3.0±.9	<1	<1	58±3	159±11	11±1	193±14
95	10±3	12±2	22±2	7±1	4.1±.9	<1	1.4±.5	61±3	72±5	9±1	260±20
110	8±3	8±2	11±1	4±1	4.0±.8	<1	<1	46±3	102±7	7±1	141±10
111	6±3	5±1	11±1	5±1	<1.6	<1	<1	54±3	77±6	7±1	134±9
112	<5	7±1	14±1	5±1	2.0±.8	<1	<1	54±3	74±5	9±1	271±19
113	11±2	7±1	10±1	3±1	<1.4	<1	<1	48±3	68±5	8±1	219±15
114	10±2	7±1	9±1	4±1	1.5±.7	<1	<1	60±3	79±6	5±1	113±8
BARBARA J											
96	18±5	21±3	23±3	5±2	14±2	3.1±.9	<2	32±2	178±13	9±1	98±7
97	7±3	9±2	19±2	4±1	2.3±.8	<1	1.5±.5	59±3	50±4	8±1	260±20
SAN MATEO, NEW MEXICO											
98	8±3	10±1	32±2	10±1	6±1	14±2	<0.7	57±4	153±11	23±2	145±10
102	11±3	10±1	28±2	6±1	6±1	<0.7	<0.7	48±3	89±6	11±1	147±10
100	<6	8±1	19±2	5±1	3.1±.8	3.9±.6	<1	62±3	86±6	12±1	232±16
101	10±3	9±1	24±2	7±1	5.1±1.0	3.7±.6	1.4±.6	70±4	110±8	14±1	230±16
103	12±3	9±1	20±2	6±1	6.2±.9	1.2±.5	<1	61±3	87±6	8±1	119±8
106	<5	11±1	21±2	10±1	4.5±.8	17.7±1.1	<0.9	54±4	111±8		151±11
105	8±3	10±2	26±2	7±1	3.8±.9	<1	2.6±.5	75±4	102±7	12±1	259±18
108	11±3	10±3	24±2	7±1	5.2±.8	<1	1.1±.5	83±4	106±7	11±1	131±9
109	8±3	12±2	26±2	7±1	2.2±.8	<1	<1	76±4	112±8	12±1	150±11
104	9±2	6±1	20±2	7±1	3.6±.9	<1	<1	66±4	78±6	9±1	209±15

TABLE 4 (continued)

BNW #	Ba	Hg	Pb	U	Nb	Mo	Sb	Ce
MORTON RANCH, WYOMING								
61	760±40	<5	14±3	140±11	7.4±1.1	<2.7	<4	51±5
62	720±40	<5	17±2	<6	3.9±.8	3.5±.9	<3	38±4
63	470±20	<5	21±3	<7	13±1	2.5±1.1	<3	160±10
64	550±30	<5	14±3	<7	11±1	4.2±1.1	<3	72±5
65	590±30	<5	14±3	<7	8.5±1.1	6.2±1.4	<5	76±7
66	690±30	<5	17±2	21±4	6.7±.9	<2.0	<3	38±4
67	760±40	<5	17±2	<6	3.7±.7	3.8±.9	<3	27±3
68	770±40	<5	17±2	<7	3.7±.8	2.1±1.0	4±2	27±4
69	560±30	<5	18±2	13±4	3.5±.8	<1.9	<3	34±4
70	730±40	<4	14±2	8±3	2.1±.7	<1.8	4±2	56±4
71	800±40	<5	23±3	16±4	13±1	<2.2	<3	42±4
72	760±40	<4	19±2	<5	8.2±.8	<1.7	<3	62±5
73	530±30	<5	20±3	<6	10±1	3.4±1.0	4±2	56±4
74	810±40	<5	17±2	<7	4.8±.8	<1.7	<3	35±3
75	690±30	<4	18±2	<5	3.9±.6	4.9±.8	<3	37±3
76	750±40	<4	23±2	<6	3.3±.7	1.8±.8	<3	31±3
77	720±40	<4	17±2	<6	2.1±.7	<1.7	<3	29±3
78	750±40	<4	23±2	<5	2.3±.6	7.2±.9	<3	22±3
79	550±30	<5	26±3	11±4	11±1	<2.2	<4	72±6
80	700±40	<4	23±2	<6	6.9±.8	2.9±.9	<3	61±4
81	680±30	<4	25±3	<6	7.6±.9	2.5±1.0	5±2	58±4
82	570±30	<5	20±3	<7	6.0±.9	2.8±1.1	3±2	46±4
83	701±40	<5	22±3	<7	11±1	2.9±1.2	5±2	66±6
84	693±40	<4	16±3	<6	5.7±.8	4.4±.9	3±2	43±4
85	591±30	<5	24±3	<6	11±1	3.2±1.1	4±2	66±5
86	618±30	<4	15±2	<6	9.1±.9	3.5±1.0	3±1	65±4
87	660±30	<5	23±3	<6	9.4±.9	3.2±1.0	<3	72±5
88	6800±300	10±4	22±3	61±6	6.9±.9	<2.2	<3	42±4
89	800±40	<7	16±3	370±30	5.2±1.1	<2.9	<3	43±4

TABLE 4 (continued)

BNW #	Ba	Hg	Pb	U	Nb	Mo	Sb	Ce
POISON CANYON, NEW MEXICO								
90	390±20	<6	12±2	44±5	4.7±0.8	<2.0	<3	25±3
91	380±20	<5	10±2	16±4	3.6±0.9	<2.1	<3	21±3
92	390±20	<5	15±2	<6	4.3±.8	2.5±1.1	<3	27±3
93	540±30	<5	10±2	8±3	3.9±.9	2.5±1.1	<3	24±3
94	460±20	<5	11±2	25±4	6.8±.9	<2.1	4±2	29±3
95	450±20	<4	12±2	<5	4.8±.7	5.5±1.0	<3	26±3
110	1826±90	<4	9±2	<5	2.4±.7	2.7±.9	4±1	26±3
111	791±40	<4	15±3	<6	<1.5	4.2±1.0	<3	20±3
112	609±30	<4	10±2	<6	3.7±.8	4.5±1.1	<3	23±3
113	853±40	<4	10±2	<5	2.7±.6	0.9±2.6	4±1	23±3
114	1277±60	<4	9±2	<5	<1.3	4.3±0.8	<3	29±3
BARBARA J								
96	280±20	<8	31±4	189±14	<2.1	<2.8	<3	14±3
97	440±20	<4	13±2	<5	4.2±.7	4.9±1.0	<3	26±3
SAN MATEO, NEW MEXICO								
98	612±31	<4	24±2	187±13	10±1	31±2	<2.1	49±4
102	416±21	<4	12±2	<2	7±1	1.1±.4	<2.2	24±3
100	566±30	<4	15±2	42±4	7.4±1.0	2.0±.9	2±1	35±3
101	484±20	<5	13±3	53±5	9.2±1.0	<2.2	4±2	44±4
103	383±20	<4	8±2	<4	6.2±.7	2.9±.8	<2	26±2
106					9±1	30±2		
105	517±20	<4	15±2	<5	7.8±.9	4.0±.9	3±1	43±4
108	579±30	<4	13±2	<5	7.6±.8	2.3±.8	<2	40±3
109	695±40	<4	16±2	<5	7.3±.8	3.6±.9	3±1	39±4
104	434±20	<4	11±2	<6	6.7±.9	2.9±1.1	<3	34±4

TABLE 5

WATER SAMPLES FROM EPA URANIUM MINE STUDY

			Concentrations µg/ℓ														
PNL #	Sample	Add Acid‡	Mo	Cu	Be	Al	Ni	Cr	Cd	Mn	Ba	V	Zn	Fe	Pb	As	Se
	San Mateo Mine, N. M.																
47	San Mateo Ck - upstream	No	94	<5	<5	180	<10	<5	<20	<2	77	56	<10	500	--	<500	22
48	San Mateo Ck - downstream	No	20	<5	<5	70	<10	<5	<20	--	250	48	<10	590	--	<500	22
	Morton Ranch, Wyoming																
27	Demineralized water†	Yes	<3	<2	<2	<3	<3	<2	<10	23	1	<5	<20	35	<2	<4	<4
28	Demineralized water - filtered†	Yes	<3	7	<2	<3	<3	<2	35	<3	1	<5	<20	<20	3	<4	<4
29	Seep well 1704 pit	Yes	15	5	<2	57	<3	<2	<10	77	63	8	<20	320	3	<4	334
30	Box Ck 8 km below 1601 pit	Yes	20	<2	<2	81	4	<2	22	149	44	6	<20	500	<2	<4	<4
31	Seep 1704 spoil bank	Yes	4	<2	<2	17	5	<2	16	9	76	5	<20	160	<2	<4	78
32	Box Ck above 1601 pit	Yes	18	<2	<2	73	<3	<2	<10	91	11	10	<20	440	<2	<4	<4
33	Box Ck below 1601 pit	Yes	15	5	<2	77	<3	<2	<10	22	86	7	<20	400	5	<4	<4
	Poison Canyon, N. M.																
35	Area 3 pond in pit	No	126	9	<2	51	<3	<2	19	23	75	25	<20	320	<2	11	138
36	Area 2 well near pit	No	18	5	<2	49	<3	<2	10	15	152	8	<20	250	<2	<4	8

‡ Acid added following separation of particulate raterial.
† From Morton Ranch.

TABLE 6
MAJOR AND TRACE ELEMENTS IN WATERBORNE PARTICULATES
(μg/liter)

PNL #	Al	Si	P	S	Cl	K	Ca	Ti	V	Cr	Mn
Morton Ranch											
PNL # - 28	47±19	<19	<17	<16	9±4	<1.9	4.7±1.0	<0.6	<0.4	<0.3	<0.2
29	1200±100	4700±400	<49	<47	<21	480±30	500±36	122±9	47±4	6.8±1.0	22±2
30	430±60	1460±150	<26	26±11	19±5	98±8	187±14	26±2	1.7±0.6	<0.7	6.7±.7
31	1200±100	4400±300	42±21	<27	<13	400±30	860±60	116±9	8.1±1.4	3.3±.7	29±2
32	110±30	270±30	16±8	<8	10±3	24±3	95±7	5.1±.7	<0.6	<0.5	11±1
33	220±40	720±110	<25	<20	13±5	51±5	600±40	11±1	1.0±0.4	<0.6	18±1
Poison Canyon											
PNL # - 35	300±50	740±110	64±18	60±17	<11	119±7	550±28	17±1	1.8±0.6	1.6±.4	37±2
36	460±60	1100±100	<36	<34	<15	120±9	590±40	26±2	2.0±0.6	<0.7	4.3±.5

	Fe	Ni	Cu	Zn	Ga	As	Se	Br	Rb	Sr	Y
Morton Ranch											
PNL # - 28	4±0.4	<0.12	0.8±.1	0.7±.1	<0.1	<0.16	<0.12	<0.13	<0.2	<0.3	<0.4
29	1360±130	2.2±.3	3.5±.3	11±1	0.8±.1	<0.4	38±3	<0.18	4.0±.3	11±0.3	1.4±.3
30	560±40	<0.4	1.7±.2	5.8±.5	<0.1	0.3±.1	<0.1	<0.14	1.0±.1	2.8±.2	<0.4
31	1270±90	1.1±.2	3.2±.3	7.0±.6	0.7±.1	0.4±.1	0.6±.1	0.4±.1	4.2±.4	11.2±.4	<0.6
32	130±9	0.22±.09	1.5±.2	1.1±.1	<0.1	0.2±.1	<0.1	<0.13	<0.2	1.2±.2	<0.4
33	260±20	<0.3	1.5±.2	1.4±.2	0.2±.1	<0.2	<0.1	0.15±.07	0.3±.1	4.3±.2	<0.4
Poison Canyon											
PNL # - 35	170±7	1.0±.2	4.4±.3	5.9±.4	<0.1	<0.2	0.8±.1	0.5±.1	<0.2	3.2±.3	<0.4
36	330±20	0.27±.10	1.8±.2	7.5±.6	<0.2	<0.4	<0.1	0.2±.1	0.6±.1	2.7±.2	<0.5

TABLE 6 (continued)

PNL NO.	Zr	Nb	Mo	Sb	Ba	Hg	Pb	U
Morton Ranch								
28	<0.5	<0.5	<0.5	<2.7	<3	<0.4	<0.5	<1.0
29	9.8±.4	0.6±.3	<0.8	<2.9	22±2	<0.7	4.3±.8	17±1
30	1.2±.2	<0.5	<0.5	<2.9	<3	<0.5	1.0±.3	<1.1
31	6.9±.4	<0.7	<0.7	<3.1	16±2	<0.7	1.4±.4	<1.7
32	<0.4	<0.5	<0.5	<2.9	<4	<0.4	<0.5	<1.0
33	0.6±.2	<0.5	<0.5	<2.7	4±2	<0.5	<0.5	<1.0
Poison Canyon								
35	0.9±.2	<0.6	<0.9	<2.9	<4	<0.5	3.0±.3	22±1
36	0.8±.3	<0.6	<0.6	<3.0	<4	<0.6	11.4±.9	<1.2

FIGURE 1. POISON CANYON NEW MEXICO MINE DRAINAGE SYSTEM - SECTION 5-17

Chemical analyses of these soils are shown in Table 4 as samples 110-114. All the samples are typified by a high content of calcium, titanium, zirconium, and barium. Most of the trace element concentrations were not significantly higher downstream of the mine piles than the upstream background levels. Barium, strontium, and calcium varied up to about a factor of 4 in concentration. The elevated concentrations were associated with the single sample collected 23 meters below a waste pile. This sample shows evidence of the spread of limestone constituents in the waste. The highest titanium, zirconium, and niobium concentrations were in the main drainage just downstream of the open pit operations and may reflect constituents of the disturbed strata. None of the elemental concentrations measured at the farthest downstream site were significantly above those found in the background samples.

The high ^{226}Ra accompanied by an elevated barium and calcium content adjacent to a waste pile is the principal feature observed here. No significant contamination from the underground site was detected. The ^{226}Ra content of the soil was about two times the background level at the farthest downstream site. This sample was collected about 130 meters from the apparent source, a waste pile adjacent to the secondary gully.

Water samples were collected at an associated site known as Poison Canyon Area II, New Mexico, which is shown in Figure 4, Task 8. A water sample, PNL #36, was collected at a well in Area II of Poison Canyon. Sample PNL #35 was collected east of Area II in an open pond which was partially filled with water. The radionuclides ^{232}Th, ^{226}Ra, ^{234}U, ^{238}U, and ^{230}Th were analyzed in both soluble and particulate fractions of these two samples. For both samples, 35 and 36, ^{226}Ra was concentrated about threefold in the soluble fraction. The ^{234}U, ^{238}U, and ^{230}Th were also concentrated in the soluble fractions. For samples 35 and 36, the uranium concentrations were on the order of 1300 pCi/ℓ, and ^{230}Th was 6.8 pCi/ℓ. These values are much higher than in comparable water samples collected at Morton Ranch, Wyoming, and from the San Mateo Creek, New Mexico. The concentrations of trace elements (micrograms/liter) in the water and in the waterborne particles are shown in Tables V and VI. Molybdenum, aluminum, barium, iron, and selenium were found in the soluble fraction of the collected sample. Selenium concentrations in the pond in the Poison Canyon region was 138 μg/ℓ; molybdenum was 126 μg/ℓ, and barium was 75 μg/ℓ. The well at the Poison Canyon inactive mining site contained only 8 ppm selenium, 152 ppm barium, and 18 ppm molybdenum. The particulate material contained 0.9 and 0.6 μg/ℓ on the particulate fraction in samples 35 and 36 from Poison Canyon. Barium was <4 μg/ℓ. Particulate lead varied from 3 μg/ℓ in the pond to 11.4 μg/ℓ in the well. Uranium was found at the 22 μg/ℓ concentration in the pond and <1.2 μg/ℓ in the well. Selenium and arsenic concentrations were also low in the waterborne particulate fraction with selenium being 0.8 μg/ℓ in the pond and <0.1 μg/ℓ in the well. These data would indicate that the pond area which collect surface run-off may accumulate leachable elements from inactive sites.

The SAN MATEO drainage system (Figure 2) originates in a large waste pile extending as a shelf on the edge of a mesa away from the mine shaft. Several small washes have formed on the face of the fill, which converge into a main wash originating at the eastern side of the mine site.

Another channel leads from the vicinity of a tank adjacent to the heap leach ponds and connects to the main channel 200-300 meters from the waste pile. Two or more gullies which do not originate at the mine site also connect with the main channel.

Soil composites were collected at the waste pile and heap leach pile. These represent the source terms for possible contamination of the watershed. Drainage samples were collected by following one channel down the waste pile face to the intersection with the primary drainage channel. Then the primary channel was sampled for a distance of 500-600 meters from the site. Additional samples were collected in the gullies leading from the heap leach area and one of the off-site gullies. The latter represents blank soil upstream of the drainage water. Most sampling sites are noted on the map in Figure 2; however, additional samples were collected at intermediate points in the gully. Soil samples 98 to 109 and water samples 47 and 48 were analyzed.

The ^{232}Th concentrations in the waste and heap leach composite were slightly elevated over samples taken from the drainages (Table 2) but, in general, all samples contained thorium values approximating ambient background levels of 0.55 pCi/g. The ^{226}Ra concentrations were 117 pCi/g in

FIGURE 2 - SAN MATEO MINE NEW MEXICO
MINE DRAINAGE SAMPLE SITE NUMBERS

the waste composite and 127 pCi/g in the heap leach composite. Following the drainage away from the mine, a concentration of 55 pCi/g was measured in soil from a dry sump at the foot of the waste pile. An additional 100 meters downstream, the concentration had fallen to 36 pCi/g relative to a background level of 0.77 pCi/g. In the main drainage gully approximately 500 meters from the waste pile, at the intersection of the background gulley and that leading to heap leach area, the concentration had fallen to 1.6 pCi/g. Approximately 200 meters farther downstream from this intersection, the ^{226}Ra content of the soil sample was not significantly different from the background. The ^{40}K content of these soils ranged from 12 pCi/g to 15 pCi/g. It appeared that a slightly elevated potassium content could be seen in and near the waste. Elevated uranium was observed in the samples taken within 100 meters downstream of the waste pile. Beyond this point, uranium levels were below the detection sensitivity limit of the X-ray excitation method.

Sample #108, creek bed mud collected at the bridge over the San Mateo Creek downstream of mine drainage, had a significantly higher ^{226}Ra content than the creek bed mud collected about 2 km upstream from the mine drainage. At 8.1 pCi/g, the level is significantly higher than was observed in most drainage samples except those closest to the waste pile. It is possible that mine waste was used as fill during construction of the bridge across the San Mateo Creek. The ^{226}Ra measurements along this system follow a pattern very similar to the gamma survey results. Since this area did not appear to have local outcroppings of ore, it is probable that material from the mine, used as fill, is the source of these elevated concentrations.

At the San Mateo site, ^{226}Ra concentrations in the watershed fell to twice background levels after a distance of 400-500 meters. Here, however, they fell more slowly during the first 100 meters than at Poison Canyon.

Most radionuclide concentrations were below the limits of detection for water samples collected from the San Mateo Creek both upstream and downstream of the point of entry of the mine drainage, so contributions of mine contaminants to the San Mateo Creek could not be thoroughly evaluated. Radium-226 was measured at 12 pCi/ℓ downstream of the mine drainage (Table 3). All radionuclide concentrations were below the environmental release levels specified for soluble species in 10 CFR 20, Appendix B (1978).

Measurements of major and trace elements (samples 98 to 109 in Table 4) indicate several elements which have elevated concentrations in the samples closest to the mine waste and ore storage areas. Uranium, selenium, and vanadium were all significantly higher than background, with concentration ratios in the waste pile relative to the background of uranium (>90), selenium (>20), and vanadium (>5). Essentially all trace elements were found at background levels 200-300 meters downstream of the waste pile.

The mud sample collected from the San Mateo Creek was significantly higher in arsenic downstream from the mine drainage than the upstream sample. This element does not appear to be related to mine waste because the concentration gradients in the drainage system were of a low magnitude. No other element was significantly higher in the downstream mud sample than in the upstream one. Similarly, the only element found to be significantly higher in downstream water than upstream was barium, which could not be identified as elevated in the run-off channel. It is probable that these sources, like the elevated downstream ^{226}Ra, reflect local sources. In the latter case, however, it can reasonably be assumed that the source is from mined minerals transported near to the site. The trace elements may be from local mineralization or the farming activities nearby.

The trace element concentrations for locations 47 and 48, samples taken upstream and downstream, respectively, from the San Mateo mine drainage site are shown in Table 5. No appreciable trace element contamination was detected in the waters collected based on a comparison of the upstream/downstream ratio. In general, the upstream sample contained a greater concentration of a given trace element than that downstream. These water samples were not evaluated for their relative soluble and particulate fractions.

In summary, at the New Mexico inactive mine drainages, the most prominent indicator of run-off from aboveground mineral storage was the ^{226}Ra content of the stream bed. It is apparent that its concentrations in the source material are almost 2 orders of magnitude higher than occurred in background soils. Elements such as uranium and selenium could have as large a concentration gradient, also. The concentration decreases generally going downstream.

A small mine located in the Poison Canyon area, the Barbara J, an inactive mine that was mined in the 1950's and 1960's, was also investigated. Two samples, #96 and #97, a waste pile composite and a background soil, were taken and analyzed. They are shown in Tables 1 and 4. The Barbara J site map is shown in Task 8, Figure 1. Sample 97, the background soil, looked very typical of other background soils in the Poison Canyon region. Sample 96, the waste pile composite, did contain significant quantities of elements associated with uranium ore. Vanadium was found to be 180 μg/ℓ of soil, arsenic 14 μg/ℓ , selenium 3 μg/ℓ, and uranium 189 μg/ℓ.

B. Wyoming Mine

Only one site was chosen for study in Wyoming--that at Morton Ranch. This site contains the semiactive 1704 pit area and 1601 pit that is currently inactive but may be reopened in the future.

The trace element and radionuclide analyses of run-off from the Wyoming area are primarily based on surface sediments and vertical sediment profiles from the dry stream beds since few streams or run-off drainages were encountered. The waterways surrounding the inactive 1601 pit area, as well as the semiactive 1704 pit area, are illustrated in Figure 3, and Task 8, Figures 8, 9, 10, and 11. Soil samples 61 to 89 and water samples 27, 28, and 30 to 33 were collected.

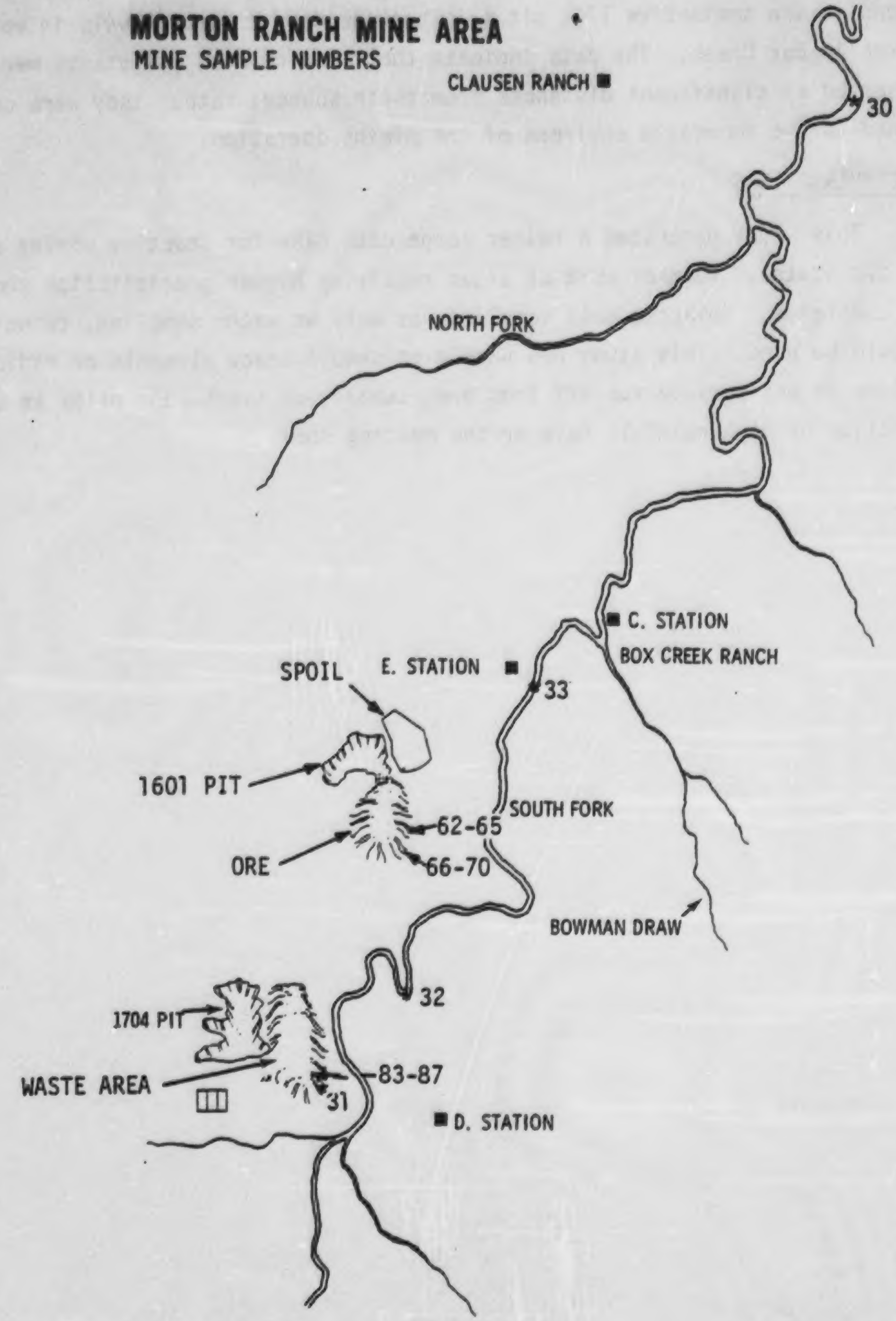
Three vertical soil profile samples were collected from alluvial deposits, two in an erosional drainage area from the ore and waste pits south of the 1601 pit, and the third on the east side of the 1704 pit's waste pile. The radionuclide and chemical constituents of these samples are reported in Tables 2 and 4, along with analyses of other soil samples. The results are discussed in detail in Task 10. Briefly, they show evidence of aqueous leaching based on the radium/uranium ratios of as high as 100 on the surface of the top alluvial fan area of the drainage, compared to a corresponding ratio of 0.9 in the undisturbed (subsurface) material in the top alluvium profile.

Trace element data in Table 4 also indicate limited transport of mine contamination with respect to uranium and, to a lesser extent, selenium and vanadium. The profile samples containing 140 and 21 ppm uranium resulted from material transported from the adjacent ore piles. It should be observed, however, that these erosional samples were collected in the immediate area shown as "ore" near the 1601 pit in Figure 3. No evidence was found to indicate transport of pollutants to local stream beds such as the fork of Box Creek.

Water samples were collected from the south fork of Box Creek, both above (PNL #32) and below (PNL #33) the drainage of the 1601 pit area. Another sample (PNL #30) was taken 8 km downstream of the drainage from a neighboring uranium mill. Uranium concentrations in the particulates associated with these samples were very low negating aqueous transport of ore material. Dissolved uranium was present at respective concentrations of 34, 39, and 11 pCi/ in these upstream-to-downstream samples. The significance of the increase of 5 pCi/ after passage of the 1601 pit is difficult to assign owing to the abundance of uranium outcroppings in this area. If one assigned the primary source of this stream contamination to the 1704 area seeps, which contained 287 pCi/ of uranium, then a steady depletion of dissolved uranium is noted with downstream passage. Similarly, radionuclides of mine origin are depleted with distance in the soils collected from the erosion channel leading from the 1601 pit decreasing to background levels prior to its discharge into Box Creek. Selenium, vanadium, and arsenic, trace elements usually associated with uranium mining, are in some cases present in high concentrations in the 1704 pit seep, but are near ambient levels in water taken in Box Creek. This again demonstrates that mine-related pollutants have not been observed at significant distances from this source; rather they are confined to the immediate environs of the mining operation.

SUMMARY

Data on trace elements and radionuclides from ore, subore, and overburden piles in surface run-off are discussed in this task and in Task 10. Two mine drainage areas in the Grants, New Mexico area and one area in Wyoming were studied. The chemical analyses and radiochemical studies of soils, water samples, and waterborne particulates indicate that the various locations are site specific and results must be considered individually for the specific areas. In the Poison Canyon, New Mexico region, ^{232}Th levels in soils were essentially constant and the lowest encountered at any site. Radium-226 levels were not significant in a watershed near above and below the mine. Uranium-238 concentrations were 2 pCi/g in all samples. In Poison Canyon most of the trace element concentrations were not significantly higher downstream of the mine piles than upstream background levels. One high ^{226}Ra measurement correlated with an elevated barium and calcium content adjacent to a waste pit; however, no significant contamination from the underground site was detected. At the San Mateo site in New Mexico, the ^{232}Th concentrations in the waste and heap leach composite samples were slightly elevated over that taken from the drainages, but in generall all samples contained thorium at approximately ambient background levels of 0.55 pCi/g. Radium-226 concentrations were 117 pCi/g in the waste composite and 127 pCi/g in a heap leach composite. Approximately 700 meters from the heap leach area, the ^{226}Ra content of the soils was not significantly different from background. Variations in trace element concentrations in samples collected upstream and downstream from the mine areas at the San Mateo site indicated that their source was local. The trace elements may also be from localized mineralization or farming activities nearby. At the New Mexico inactive mine drainages, the most prominent indicator of run-off from aboveground mineral storage was ^{226}Ra content of the stream bed. It was apparent that its concentrations were almost 2 orders of magnitude higher in source materials than occurred in background soils. Elements such as uranium and selenium also had a large concentration gradient. These gradients all decreased going downstream from specific mine sites. At Poison Canyon, the ^{226}Ra concentration diminished to twice background in a distance of 100 meters, while at the San Mateo site the twice background distance was about 400-500 meters. At the Morton Ranch, Wyoming site, the radionuclides and chemical constituents show evidence of aqueous leaching based on the radium-uranium ratios. The trace element data indicate a limited transport of mine contamination with respect to uranium and to a lesser extent selenium and vanadium. It should be noted here that the samples contained some material of ore and subore origin. This is not surprising since they were collected in the immediate area near ore from the 1601 pit. No evidence was found to indicate transport of ore or subore to local stream beds such as the various



MORTON RANCH MINE AREA
MINE SAMPLE NUMBERS

CLAUSEN RANCH
30
NORTH FORK
C. STATION
BOX CREEK RANCH
E. STATION
33
SPOIL
1601 PIT
SOUTH FORK
62-65
ORE
66-70
BOWMAN DRAW
32
1704 PIT
WASTE AREA
83-87
31
D. STATION

FIGURE 3

forks of Box Creek. Selenium, vanadium, and arsenic, trace elements usually associated with uranium mining, are present in some cases in high concentrations in the semiactive 1704 pit seep but are near ambient levels in water taken in Box Creek. The data indicate that mine-related pollutants were not observed at significant distances from their source; rather they were confined to the immediate environs of the mining operation.

RECOMMENDATIONS

This study generated a rather large data base for inactive mining sites in two states. Further work at sites receiving higher precipitation should be completed. Selected soil sampling, as well as water sampling, techniques should be used. This study was unable to sample trace elements or radionuclides in any surface run-off from ore, subore, or overburden piles as a function of high rainfall rate or the melting snow.

TASK 6

RADON EMISSION FROM INACTIVE UNDERGROUND URANIUM MINES

INTRODUCTION

The purpose of this experiment was to determine the quantity of radon emitted from some inactive underground uranium mines as a function of known sampling site parameters and micro-meteorology. Criteria for selection of a mine suitable for sampling and evaluation included the following characteristics:

1. It should be isolated underground, not connected to other inactive or active mines.
2. It should not be totally flooded since that would preclude underground air passage.
3. It should have open vents and an open shaft, free from danger of imminent collapse.
4. It should be accessible.

Ten mines were evaluated in the Grants, New Mexico, uranium belt and none satisfied all of the above criteria. Two mines finally were selected for study based on their accessible unsealed shafts and partially unsealed vents. No maps were available describing these sites either aboveground or underground. However, discussions with local mining personnel and our observations at the sites led to the following descriptions.

Mine 1

EXPERIMENTAL PROTOCOL

Mine 1 (Mesa Top Mine) is an inactive underground mine of large size. It is connected underground to three other inactive mines, and through them eventually to two active mines. This system of mines covers an area of about one square mile. From 0800 - 1600 week days, a ventilation fan is operated by the active mine which draws fresh air into the shaft and vents of the Mesa Top Mine. During evenings and weekends, the fan is turned off and natural ventilation occurs. This mine is on top of a mesa and all but one of the connecting mines are adit mines, cutting into the face of the mesa. A natural chimney effect exists, and substantial air currents pass out of the shaft of the Mesa Top Mine at flow rates of up to 88,000 ℓ/min. The shaft is about 2 meters square, and was fenced at a distance of 2 meters. The ventilation technique apparently used by the original operators was to drill numerous uncased 30 cm diameter holes from the surface to the working areas which were about 40 to 50 meters below the surface. In one location alone, over ten such holes were encountered in a distance of 130 meters. To reduce the sampling effort to a reasonable number, every third hole along this line was sampled. The present depths of these vents ranged from 1.5 meters to 10 meters, indicating that all had collapsed. Two additional vents were located, Vents 5 and 6, which penetrated to depths greater than 30 meters. A cased 0.9 meter diameter escape vent was located 110 meters from the shaft. Aside from small cracks around the door, the escape vent was sealed.

Continuous radon monitors were installed at the shaft and the escape vent. Grab samples were collected at the shallow vent holes, and at each of the two deeper holes, a sequential tedlar bag sampling apparatus collected integrated samples. The continuous concentration measurements from the Mesa Top Mine shaft and escape vent are summarized in Table 1, and grab sample results from the ventilation shafts are shown in Table 2.

DISCUSSION

Radon concentrations of up to 11,000 pCi/ℓ were found in air from the shaft. The flow rate of air from the shaft was measured several times during the weekend of April 28 to 29, 1979, and found to be relatively stable, averaging 76,000 ± 3800 ℓ/min. The product of the average weekend concentration and the average flow yielded an emission rate of nearly 1 Ci/day, as shown in Table 3. This level is of the same order as the emission from a large active mine. During mid-week, the concentration falls rapidly to ambient levels at 8:00 a.m. (more rapidly than indicated by the continuous monitor which has a slow response to change because of radon daughter buildup in the detector). After 4:00 p.m. each day, the level again increased but never reached the concentrations seen on the weekend. The buildup after turning off forced ventilation required about 17 hours to reach a stable level. Each day, a similar maximum level was reached, indicating that the air flows rapidly attained equilibrium with the radon emission rate of the

RADON CONCENTRATIONS AT MESA TOP MINE SHAFT AND ESCAPE VENT

TABLE 1

Concentration (pCi/l)

Time	4-23 Shaft	4-23 Escape Vent	4-24 Shaft	4-24 Escape Vent	4-25 Shaft	4-25 Escape Vent	4-26 Shaft	4-26 Escape Vent	4-27 Shaft	4-27 Escape Vent	4-28 Shaft	4-28 Escape Vent	4-29 Shaft	4-29 Escape Vent	4-30 Shaft	4-30 Escape Vent	5-1-79 Shaft	5-1-79 Escape Vent
0000	-	-	-	1400	4600	3200	4500	1700	9100	3100	4300	1600	9200	-	10000	2000	-	1900
0100	-	-	-	1500	5200	3700	5200	1900	9400	3500	4900	1700	9600	-	11000	2200	-	2100
0200	-	-	-	1600	5900	4300	3900	2700	9800	6200	5700	1900	9800	-	11000	2500	-	2200
0300	-	-	-	1800	6400	4100	6400	3600	9900	7100	6600	3700	9900	-	12000	2500	-	2700
0400	-	-	-	1800	6900	3900	6900	4100	9800	8300	7200	4100	10000	-	12000	2600	-	2800
0500	-	-	-	1700	7300	3000	7300	4600	10000	8500	7700	4200	10000	-	12000	2700	-	3000
0600	-	-	-	1800	7600	4100	7500	5000	10000	8400	8200	4400	10000	-	12000	2700	-	6600
0700	-	-	-	1700	7800	4300	-	-	10000	8800	8500	5500	10000	-	12000	2700	-	-
0800	-	-	-	1700	8000	5200	-	-	9000	8700	8500	6500	10000	-	4200	2600	-	-
0900	-	-	-	500	2300	2000	-	-	7600	2200	-	-	11000	-	2100	2500	-	-
1000	-	-	-		750	520	-	-	810	700	9000	5600	11000	-	6900	2500	-	-
1100	-	-	-		220	150	-	-	230	190	8900	4000	11000	-	8100	2400	-	-
1200	-	-	-		601	42		2000	65	56	8500	2700	10000	-	9100	2400	-	-
1300	-	-	-		161	14	6300	-	22	19	7000	1900	10000	-	9300	3400	-	-
1400	-	-	-		7.6	7.2	-	-	11	8.5	6600	1600	10000	-	-	2400	-	-
1500	-	-	1.8	4.9	5.5	5.2	-	-	9.5	8.1	5700	400	10000	-	-	2400	-	-
1600	-	2.7	1.7	3.8	4.3	50	-	-	7.3	7.1	5200	200	11000	-	-	2600	-	-
1700	-	2.4	1.9	3.4	16.0	4.5	-	36	9.4	10	4900	200	10000	-	-	2400	-	-
1800	-	2.2	550	690	950	460	6400	2100	470	73	4500	-	9000	120	-	2100	-	-
1900	-	210	1500	1000	1600	470	6700	1700	1600	1000	4800	-	9500	900	-	2000	-	-
2000	-	790	2200	1200	2100	470	6900	1600	2200	1200	5000	-	9200	1100	-	-	-	-
2100	-	1100	2700	1400	2600	1000	7300	1600	2900	1200	5500	-	9500	1300	-	1800	-	-
2200	-	1200	3200	1600	3200	1300	8000	1900	3300	1300	6800	-	10000	1500	-	1800	-	-
2300	-	1300	4100	2500	3900	1500	8700	2600	3800	1400	8600	-	9900	1700	-	1800	-	-
Average		570	1600	1300	3200	1900	6800	2500	4400	3000	6700	2700	10000	1100	9400	2300	-	3100
Daily Maximum				1800	8000	5300	8700	6000	10000	8800	9000	6700	11000	-	12000	2800	-	6600

NOTE: 1. Constant Radon monitor has a slow response characteristic because of the buildup of radon daughters within the detector. After three hours of stable radon concentrations, the limit to measurement error is ± 15%.

2. During weekdays, this mine is ventilated by forced ventilation fans used by an attached active mine. Fan hours are approximately the 8:00 a.m. to 4:00 p.m. day shift.

TABLE 2

VENT SAMPLES AT MESA TOP MINE

Radon Concentration (PCi/ℓ)

Sampling Interval		Vent 1	Vent 2	Vent 3	Vent 4	Vent 5	Vent 6
4-26 - 1220		310					
4-26 - 1227			670				
4-26 - 1231				250			
4-26 - 1233					1600		
4-26 - 1401						410	
4-27 - 1509	4-27 - 1909					39	
4-27 - 1909	4-27 - 2309					5.1	
4-27 - 2301	4-28 - 0309					2.9	
4-28 - 0709	4-28 - 1109					24.	
4-28 - 1109	4-28 - 1509					43.	
4-29 - 0357	4-29 - 0757						0.8 ± 0.6
4-29 - 0757	4-29 - 1157						12.
4-29 - 1157	4-29 - 2351						73.
4-29 - 2357	4-30 - 0357						6.8
4-30 - 0357	4-30 - 0757						9.6
4-28 - 1612	4-28 - 2012					18.	
4-28 - 2012	4-29 - 0012					3.4 ± 0.7	
4-29 - 0012	4-29 - 0412					3.7 ± 0.6	
4-29 - 0412	4-29 - 0812					1.1 ± 0.5	
4-29 - 1212	4-29 - 1612					17.	
4-29 - 1617	4-29 - 2017					21.	
4-29 - 2012	4-30 - 0012					16.	

Note 1. No measurable air flow was detected at these vents except for Vent #5 at 4-28-79 - 1430 where we were able to measure with smoke tubes a flow of 170 ± 37 ℓ/min. This positive flow corresponds with increased radon concentration at this vent hole.

Note 2. Samples collected at Vents #5 and #6 were integrated using sequential air sampling pumps which fed tedlar bags. During positive air flow periods these samplers fill with mine air. At times of zero or negative flow, the sample will be more indicative of ambient air concentrations.

Note 3. Hole depths were measured as follows:

Vent 1: 10 meters
Vent 2: 7 meters
Vent 3: 1.5 meters
Vent 4: 5.5 meters
Vent 5: >30 meters
Vent 6: >30 meters

It is expected that caving has occurred at Vents 1-4 since they are uncased. Vents 5 and 6 appear to be open to the mine. Vent 5 is cased at the surface. Vent 6 is uncased.

Note 4. Grab samples at Vents 1-4 were collected from about 1 m below the surface.

TABLE 3

RADON EMISSIONS FROM MESA TOP SHAFT

Date	Time	Flow Rate ℓ/min	Radon Concentration pCi/ℓ	Radon Emission Rate Ci/day
4-28-79	1030	72,000 ± 9800	9,000	0.9
4-28-79	1300	67,000 ± 540	7,800	0.8
4-28-79	1700	65,000 ± 6300	4,870	0.5
4-28-79	1900	84,000 ± 1500	4,810	0.6
4-29-79	0800	78,000 ± 3700	10,200	1.1
4-29-79	1115	88,000 ± 4000	10,540	1.3
Average of Data		76,000 ± 3800	7,800	0.9

NOTE: Estimated upper limit of bias error for radon measurements is ±15%.

Product of average flow rate and average of weekend radon concentrations reflects average radon emission rates from the shaft under conditions of natural ventilation.

mine walls, and that the flow was relatively constant after forced ventilation was turned off during the six-day period of observation. On April 30, 1979, it appeared the ventilation fans were turned on for a short time at 0800 but shut down again.

Air flow at the escape vent was measured only twice. An outward flow of ~6000 ℓ/m was found on September 29 at 0930 and negative, or flow into the mine was observed on April 28 at 1700 hours. This inward flow was reflected by decreasing radon concentrations measured at the escape vent, and was probably created by a chimney effect of the shaft pulling air from the escape vent. It is apparent from the radon data in Table 1 that flow was normally positive from the escape vent during most periods. An estimate of the upper limit of radon emission from this source is ~0.1 Ci/day determined by multiplying the 6000 ℓ/m flow by 8800 pCi/ℓ, the maximum observed radon concentration. At the small vents, radon concentrations ranged from ambient levels to 1600 pCi/ℓ (see Table 2). Flows were undetectable at these vents, except at Vent 4 where, on one occasion, a flow of 170 ℓ/min was measured when the radon concentration had increased. It is doubtful that these holes are a part of the same flow path feeding the shaft. The radon concentrations observed may be from local ore deposits or may indicate radon diffusion through a relatively thin blockage in the vent shaft. At any rate, emission of radon from these sources is insignificant compared with the shaft and escape vent.

Radon concentrations were measured at the four corners of the perimeter fence surrounding the shaft on one occasion when the prevailing wind speed was 2 meters/sec. A concentration of 66 pCi/ℓ was measured at the downwind corner as shown in Table 4, compared with 0.7 pCi/ℓ on the upwind side. Although the mine site is fairly remote, individuals or livestock can be exposed to elevated radon concentrations in the vicinity of the mine shaft, especially on days of relative calm.

In summary, the Mesa Top Mine is a very significant radon source with an emission rate of about 1 Ci/day. Radon escaped principally via the shaft at a relatively stable flow rate when the attached ventilation system was shut down. Normal air flow from the mine shaft appears to result from a

TABLE 4

AMBIENT AIR CONCENTRATIONS ADJACENT TO MESA TOP SHAFT*

Sample	Collected Date	Collected Time	Radon Concentration, pC/l
1. South	4-29-79	0822	0.7 ± 0.3
2. East	4-29-79	0824	48.
3. North	4-29-79	0826	66.
4. West	4-29-79	0828	14.0 ± 0.8

NOTE:
1. Prevailing wind direction was from south to north. Average wind speed from 0835 - 1018 was 2 m/sec.
2. Samples were collected at the corners of the fence surrounding the shaft. Each corner was approximately 2 meters from the shaft. Samples collected at a height of ~1.6 meters from the ground to simulate nose height.
3. Shaft air radon concentrations very stable at 9500 → 10,500 pCi/ℓ from 0000 hrs to 1900 hrs on this day. Emission rates equivalent to about 1 Ci/day prevailed.

natural chimney effect and exhausts from a significant underground mining network. High radon concentrations were measured a few meters downwind from the shaft.

Mine 2

EXPERIMENTAL PROTOCOL

Mine 2 (Barbara J) is in Poison Canyon. It is a relatively small, vercal shaft underground mine possibly connected underground with other inactive mines in the vicinity. The mine is partially flooded, and water could be seen flowing at the bottom of the shaft. The shaft has been covered with a 0.6 cm plate welded to the metal beams. Several cracks and holes have been cut to allow access for pipes. The largest hole allowes a 36 cm OD uncapped pipe to pass out one side; the cover has been pried up at one corner and is supported by a 41 cm wooden peg. Five cased vents believed to be associated with the mine were located. Four of these had caps primarily made from buckets inverted over the 30 cm diameter vents and welded in place. One was gas tight. One vent was partially covered with a small wooden plank. The remaining vents had holes in the covers ranging from ~2 cm in diameter up to 8 cm. One had a loosely fitted bucket whose inside diameter was about 1 cm larger than the outside of the vent.

Three Eberline continuous radon monitors were installed on this site. One was located at the shaft and one at Vent 1, an open vent nearest the shaft. The third was installed about 100 meters upwind from the shaft and its adjacent waste pile to collect ambient air. Because of time constraints, it was not possible to obtain additional continuous monitoring equipment for this experiment. Grab samples were collected at the other vents using preevacuated radon counting detectors described in NUREG/CR-0627, PNL-2888, Page 8. A recording vane anemometer was installed in the opening at the shaft. Hand-held integrating vane anemometers were initially used to measure vent flows, but at no time was a significant flow detected. A later recheck for flows was made by injecting smoke puffs 3 meters down each vent or shaft and measuring the rise time. These smoke tube tests showed the air to be stagnant at both the shaft and two of the open vents at the time of measurement. The time of measurement also coincided with the usual time of the radon concentration maxima recorded by the continuous radon monitors.

DISCUSSION

The radon concentrations measured in the collected samples is shown in Table 5. Concentrations at the shaft and Vent 1 show a distinct diurnal variation with a maxima at the shaft between 1800 hours and 2000 hours. At Vent 1, a second maxima occurred between 0300 and 0600 hours. Radon concentrations in air from the shaft ranged from 2.7 pCi/ℓ to a maximum of 52 pCi/ℓ with the minimum generally occurring between 1600 and 1700 hours. During the same period, concentrations at Vent 1 ranged from less than 1 pCi/ℓ to a maximum of 151 pCi/ℓ. The concentrations at Vent 1 reached a maximum at the time of the minimum at the shaft on three of the days of observations. This may indicate an oscillation was occurring with an initial period when ambient air fell into the open shaft and mine air rose from Vent 1 followed by a period when the flow pattern reversed.

Grab samples collected at Vents 2 and 3 on April 21, 1979, showed similar minimum concentrations at 1500 hours, and maxima at about 1700 hours. The maximum concentrations measured using grab samples were 3400 pCi/ℓ for Vent 2, 80 pCi/ℓ at Vent 3, and 2000 pCi/ℓ at Vent 4, which was not located at the time of the original measurements.

The principal variations appeared to be in response to air flowing into and out of the mine. A second possibility is that a concentration maximum is induced by changes in the exhalation rate of radon from the mine walls in response to barometric pressure changes. This maximum is normally seen between 1400 and 1500 hours at actively ventilated mines. The emission at the Barbara J Mine may be delayed by the transit time for air to move from the mined-out areas to the surface. A second factor which may be responsible is the sudden drop in outside temperature at sunset. This can upset the density balance between mine air and outside air, causing the latter to fall into mine openings and displace some of the warmer mine air.

Since we could not quantitate flow versus concentration data for most of the samples, a single set of grab samples was collected on April 28, 1979, when the smoke flow tests were made. The latter were much more sensitive than the anemometer tests. On this occasion, we observed no net outward flow of smoke at the shaft Vents 2 or 4 when the smoke was injected

RADON CONCENTRATI

Radon

Time	4-19-79 Shaft	4-19-79 Vent #1	4-19-79 Ambient	4-20-79 Shaft	4-20-79 Vent #1	4-20-79 Ambient	4-21-79 Shaft	4-21-79 Vent #1	4-21-79 Ambient	4-21-79 Vent #2	4-21-79 Vent #3
0000	-	-	-	7.6	1.4	0.82	-	8.5	7.6	-	-
0100	-	-	-	7.6	1.5	0.75	-	9.5	11.	-	-
0200	-	-	-	7.6	1.6	0.63	-	8.9	8.4	-	-
0300	-	-	-	7.6	3.2	0.81	-	10.3	9,4	-	-
0400	-	-	-	7.6	2.9	0.79	-	10.6	9.6	-	-
0500	-	-	-	7.6	3.9	0.80	-	9.6	8.3	-	-
0600	-	-	-	7.8	3.2	0.86	-	8.0	6.0	-	-
0700	-	-	-	7.9	-	0.81	-	3.8	3.6	-	-
0800	-	-	-	9.6	-	0.75	-	1.7	3.0	-	-
0900	-	-	0.18	11.	-	0.73	-	0.4	1.9	1050.	-
1000	-	-	0.75	12.	0.9	0.75	8.2	0.5	1.5	-	-
1100	-	-	0.65	17.	0.4	0.73	6.7	1.5	1.5		80.
1200	-	-	0.63	20.	0.0	0.70	5.4	5.5	1.2		-
1300	16.	20.	0.73	24.	0.3	0.77	8.2	13.	1.4	620.	<0.6
1400	7.2	16.	0.66	25.	1.6	0.73	4.6	14.	1.4	-	-
1500	3.2	15.	0.63	25.	6.7	1.0	7.6	34.	1.2	190.	54.
1600	2.7	14.	0.75	34.	8.6	1.0	4.5	17.	1.2	-	-
1700	2.7	9.	0.72	41.	8.4	1.0	3.8	24.	1.3	1800.	80.
1800	3.7	11.	0.69	49.	18.	1.5	5.2	42.	-	-	-
1900	8.2	9.	0.79	48.	30.	2.8	9.2	31.	1.6	1600.	68.
2000	12.2	3.8	0.87	38.	19.	3.5	15.	18.	2.2	-	-
2100	7.2	2.6	0.82	17.	10.	4.2	18.	11.	2.9	-	-
2200	6.7	1.7	0.83	9.2	8.6	4.8	12.	8.3	2.6	-	-
2300	5.7	1.8	0.82	-	8.5	5.8	10.	5.2	2.3	-	-
Ave.		-	0.74	19.1	6.6	1.5	8.5	12.	4.0	-	-
Daily Max.			0.9	51.	30	7.9	20.	42.	12.	-	-

NOTES:

1. Measurement precision is limited by the number of counts recorded. The constant radon monitor has a slow tions, the accuracy limits are estimated to be the greater of ±15 or 1 pCi/ℓ.

2. Shaft and Vent 1 data are from Eberline flowing constant radon monitors. Vents 2, 3 and 4 data are from g

2 meters or more below the surface. If injected less than 1.5 meters below the surface, smoke was observed to swirl and occasionally reach the top of the shaft and Vent 2 because of wind-induced eddies. A positive flow rate was measured at Vents 1 and 3. An upper limit to the flow rates at the shaft and Vents 2 and 4 was estimated from the length of observation and depth of smoke injection.

Using the flow rates measured and the concurrent radon concentrations, an estimate was made of the emission rate from each mine opening. It is shown along with the flow rates in Table 6. To evaluate this emission rate, the exhalation rate of radon from typical New Mexico soil was multiplied by the approximate area of the mine site. Assuming an emission rate of 0.65 $pCi/m^2/sec$ (see NUREG 0511, Appendix O), a quarter section of land would emit about 5600 μCi/day. This exceeds the estimated emission rates on the occasion of sampling on April 28, 1979. These samples were collected at the time of maximum concentrations indicated by previous sampling. During the periods of continuous monitoring of the shaft and Vent 1, major differences were observed in the total emissions at that time. To better estimate an upper limiting emission rate, the highest concentrations measured at each opening were multiplied by the upper limit of the flow rates measured. These data, shown in Table 7, yield an estimate of less than 2800 μCi/day. These maximum emission rates are smaller than the natural emissions expected from the local soil of the area.

The observed ambient radon concentrations ranged from 0.18 pCi/ℓ to a maximum of 12 pCi/ℓ. The highest concentrations were observed between midnight and 0600 when the average wind velocity in the area was minimal. Concentrations started to rise at about 1800 hours each day. Although this time corresponds to the maximum emission rate from the mine, the influence of other active and inactive mines in the vicinity must be evaluated before the contribution from the Barbara J can be determined.

A meteorology station was not available at the time of this task, thus an interpretation of the fine structure of the concentration patterns observed at this site can not be made.

In summary, the Barbara J Mine is a small vertical shaft mine with very small air flows from vents and shaft which are only partly unsealed. The

TABLE 6

RADON EMISSIONS AT THE BARBARA J MINE

Sample Location	Date	Time	Flow Rate ℓ/min	Radon Concentration pCi/ℓ	Radon Emission Rate μCi/day
Shaft	4/28/79	1837	<3500(1)	3.8 ± 0.5	<24.
Vent 1	4/28/79	1812	220	2.6 ± 0.5	1.
Vent 2	4/28/79	1732	<133	68.	<13.
Vent 3	4/28/79	1755	8.9	53.	0.7
Vent 4	4/28/79	1747	<133	2000.	<380.
Total Mine					<800.

(1) Based on smoke rise-time measurements

TABLE 7

MAXIMUM POTENTIAL OBSERVED RADON EMISSIONS AT THE BARBARA J MINE

Sample Location	Date	Time	Maximum Flow(2) ℓ/min	Maximum Observed Concentration pCi/ℓ	Maximum Radon Emission μCi/day
Shaft	4/22/79	21:27	<20000(2)	52	<1500
Vent 1	4/22/79	15:35	<1300(2)	151	<280
Vent 2	4/22/79	11:53	<133(1)	3400	<650
Vent 3	4/21/79	17:07	<290(2)	80	<33
Vent 4	4/28/79	17:47	<133(1)	2000	<380
Total mine					<2840

(1) Based on smoke rise-time measurements

(2) Based on the minimum sensitivity of the vane anemometers employed

radon emission rate was relatively small. Ambient radon concentration peaks of up to 12 pCi/ℓ were measured at the mine site. Since the site is surrounded by three active mines and at least five other inactive mines within a 1 mile radius, the ambient radon concentrations cannot be exclusively related to emissions from this mine.

The presence of two such dissimilar mines as the Barbara J and the Mesa Top within about a mile of each other indicate the difficulty of establishing criteria for radon emissions from typical inactive underground mines. It appears that given the proper configuration, an abandoned mine may represent a significant local source of radon. Unless steps are initiated to seal such mines effectively, these emissions will continue indefinitely.

The studies of radon concentrations downwind from active mine vents indicate that high radon concentrations can exist in the proximity of a mine shaft during periods of calm, but that during windy periods the dilution of the vent plume is extremely rapid. Radon concentrations at a distance of greater than about 250 feet were indistinguishable from the nominal ambient concentration in the vicinity.

SUMMARY

Radon emission rates from two inactive underground mines were measured. The first, Mesa Top, is an inactive underground mine of large size, the second, Barbara J, of Poison Canyon is relatively small. The Mesa Top Mine which connects with other inactive and active mines is a significant radon source with an emission rate of about 1 Ci/day. High radon concentrations were measured a few meters downwind from the shaft. The radon emission rate from the Barbara J was relatively small with radon concentration peaks only up to 12 pCi/ℓ measured at the mine site. The presence of two dissimilar mines such as the Barbara J and the Mesa Top within a mile of one another indicate the difficulty of establishing criteria for radon emissions from typical inactive underground mines.

RECOMMENDATIONS

During this study of radon emissions from inactive underground uranium mines, ten mines were evaluated in the Grants, New Mexico, uranium belt. None of the mines completely satisfied inactive criteria or fulfilled a requirement of isolation from other mines. This is indicated by the tremendously dissimilar data generated for the two "inactive" mines. This data base further indicates that studies should include environmental measurements to be taken during stagnate air conditions to observe local maximum effects. In addition, studies of a large number of inactive mines must be completed so that typical cases can be determined. It appears that given the proper configuration, an abandoned mine may represent a significant local source of radon unless steps are initiated to seal such mines effectively.

TASK 7

RADON EXHALATION FROM ORE, SUBORE, AND OVERBURDEN FROM AN INACTIVE URANIUM MINE

INTRODUCTION

In order to estimate the radon emissions from inactive mine sites, measuresments were made of the radon exhalation of the ore, subore, and overburden at the sites. Unfortunately, most inactive uranium mines existing in the United States are associated with active mining areas. Although an attempt was made in this study to measure inactive mines or those that had been placed on a temporary inactive status, all study areas were near active mining sites. Four mines were sampled in New Mexico: San Mateo, Poison Canyon #1, Poison Canyon #2, and Barbara J. These four mines were all inactive. The mine in the Morton Ranch area of Wyoming was also sampled. Its 1601 inactive pit which was studied for its radon emissions was associated with active mining 8 to 10 years ago and is discussed in Task 8.

EXPERIMENTAL PROTOCOL

Radon exhalation from ore, subore, and overburden at inactive uranium mines was determined by sampling the radon exhalation from a defined area for a known time period using charcoal canisters, and subsequently analyzing the gamma-ray emissions from radon decay. Sampling was conducted during April and May, 1979, at the Morton Ranch 1601 pit in Wyoming, and at the San Mateo, Poison Canyon #1, Poison Canyon #2, and Barbara J mines near Grants, New Mexico. The Wyoming samples were analyzed at Pacific Northwest Laboratory, and the New Mexico samples, except as noted, were analyzed by EPA's EERF Laboratory, Montgomery, Alabama. Details of the sampling and analysis procedures are given in the Appendix.

DISCUSSION

Wyoming Mines

Mining at the 1601 pit at Morton Ranch, Wyoming, was suspended some 10 years ago; however, it is scheduled to be reopened in reflection of the current uranium economy. Sampling locations within the 1601 pit are shown in Figure 1. Additional measurements were made in the surrounding area on ore piles, spoil piles, etc. Radon fluxes measured from these samples are tabulated in Table 1 and are plotted on an expanded area map in Figure 2. As illustrated, there are tremendous variations among the radon fluxes due to the small areas sampled and the inhomogeneities in soil properties and radium concentrations. The area designated "topsoil 1" was so labeled by site personnel but does seem to exhale inordinately high radon values for topsoil.

Very rough estimates of the radon emission rates from the Morton Ranch 1601 pit area given in Table 2 was made by multiplying the measured fluxes by the appropriate surface areas of ore, topsoil, and spoil dumps. Two methods were used to estimate radon emission from the pit itself: 1) the total surface area of the pit, when multiplied by the average of all measured fluxes, yielded a value of 5.5×10^5 pCi/sec, and 2) individual fluxes across the best estimate of their appropriate surface areas yielded an emission rate of 4.5×10^5 pCi/sec. The agreement of these two values is perhaps fortuitous considering the variability of fluxes within the pit.

New Mexico Mines

The San Mateo mine is a very large, flooded, inactive underground mine which still contains mineable ore. The surrounding area is characterized by many ore "nuggets" lying on overburden material. The Barbara J is a small underground mine with a small waste pile at its exterior. Poison Canyon #1 and #2 are areas of multiple open pits. These pits are approximately 12 meters deep, with the overburden piles adjacent to the various pits. Poison Canyon #2 has some islands in the open pit which might contain unexcavated material or they may be overburden, subore, or ore piles. Designation of the likely derivation of materials at various area of Poison Canyon #2 was made by EPA and PNL personnel during a visual survey.

These mines were sampled in a manner similar to that used for Morton Ranch. Fluxes determined at various sampling points at these respective mines are depicted in Figures 3 through 6 and are given in Table 3.

Exhalation rates from the ore pile surfaces at the Morton Ranch site ranged from $3\text{-}7 \times 10^{-2}$ pCi/cm^2/sec, while those in the pits and other surfaces were much lower. At Poison Canyon #2, it seems that field descriptions were not appropriate. In some instances overburden apparently should have

FIGURE 1.

RADON FLUX MEASUREMENT LOCATIONS IN PIT 1601

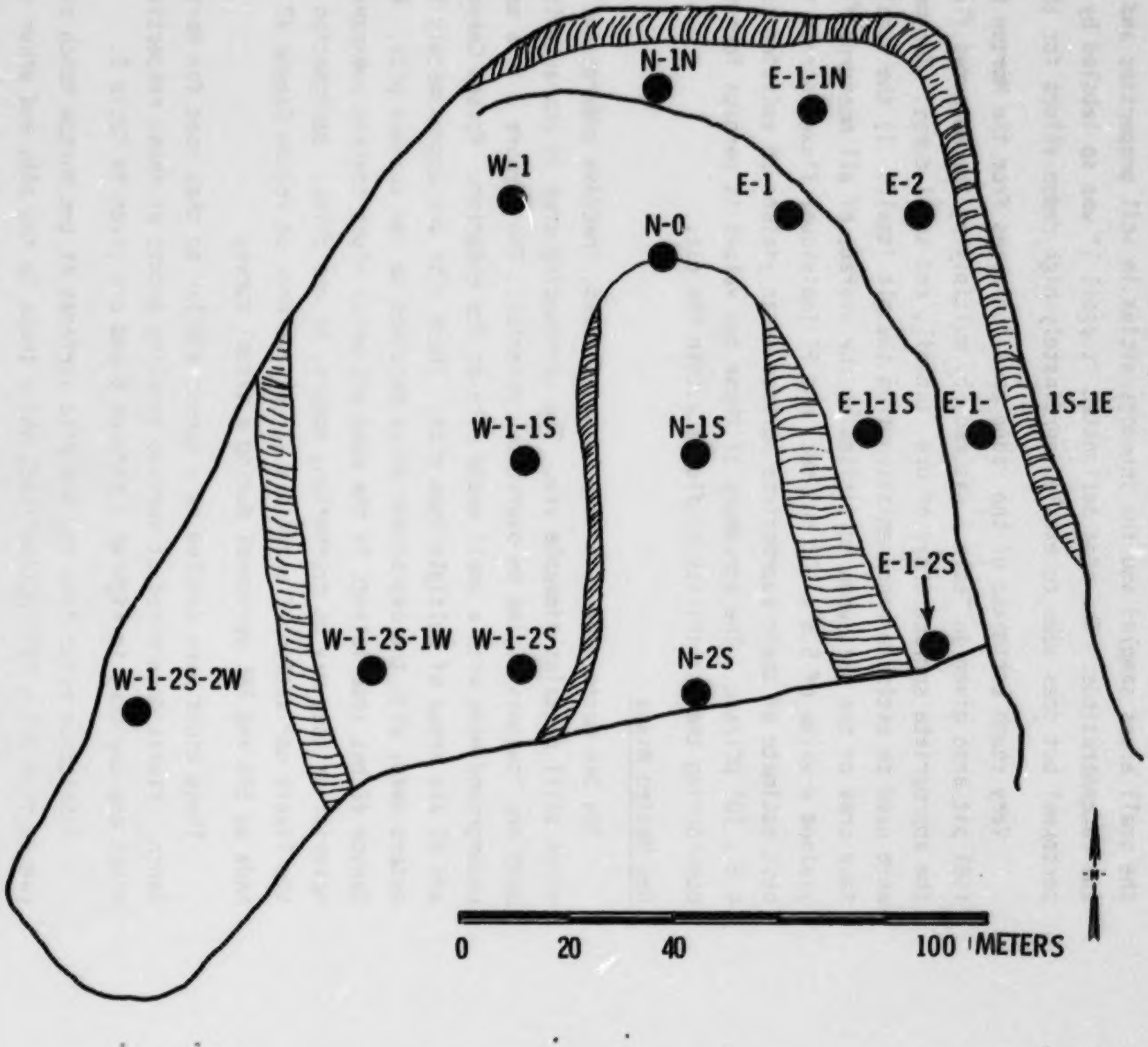

N-1N
E-1-1N
W-1
E-1
E-2
N-0
E-1-1S
E-1-1S-1E
W-1-1S
N-1S
E-1-2S
W-1-2S-1W
W-1-2S
N-2S
W-1-2S-2W
0
20
40
100
METERS
N

TABLE 1

RADON EXHALATION FROM ORE, SUBORE AND OVERBURDEN* AT MORTON RANCH, 1601 PIT, APRIL 1979

EPA Sample Number	Radon Flux pCi/cm^2/sec	EPA Sample Number	Radon Flux pCi/cm^2/sec
E-1-1S-1E	$2.77 \times 10^{-4} \pm 0.08 \times 10^{-4}$	W-1-1S	3.2×10^{-4}
E-2	$6.6 \times 10^{-4} \pm 0.1 \times 10^{-4}$	W-1-2S-1W	$9.6 \times 10^{-4} \pm 0.2 \times 10^{-4}$
E-1-1N	$1.36 \times 10^{-2} \pm 0.03 \times 10^{-2}$	E-1-1S	1.0×10^{-3}
N-1-N	$5.8 \times 10^{-3} \pm 0.1 \times 10^{-3}$	ORE #4	6.9×10^{-2}
E-1	4.4×10^{-3}	ORE #3	$4.9 \times 10^{-2} \pm 0.1 \times 10^{-2}$
N-0	3.1×10^{-4}	Top Soil #1 South End	$2.75 \times 10^{-3} \pm 0.05 \times 10^{-3}$
W-1	$8.3 \times 10^{-5} \pm 0.5 \times 10^{-5}$	ORE #1	$3.23 \times 10^{-2} \pm 0.03 \times 10^{-2}$
N-1S	1.3×10^{-4}	ORE #2	7.2×10^{-2}
E-1-2S	$1.27 \times 10^{-3} \pm 0.03 \times 10^{-3}$	Spoil North End	3.5×10^{-3}
N-2S	1.7×10^{-4}	Top Soil #2	1.5×10^{-4}
W-1-2S	9.5×10^{-5}	315° 240 m	$2.9 \times 10^{-4} \pm 0.1 \times 10^{-4}$
W-1-2S-2W	$8.8 \times 10^{-5} \pm 0.3 \times 10^{-5}$	45° 490 m	$1.61 \times 10^{-4} \pm 0.06 \times 10^{-4}$

*Sample Area 45.4 cm^2

FIGURE 2. RADON FLUXES FROM THE MORTON RANCH 1601 PIT

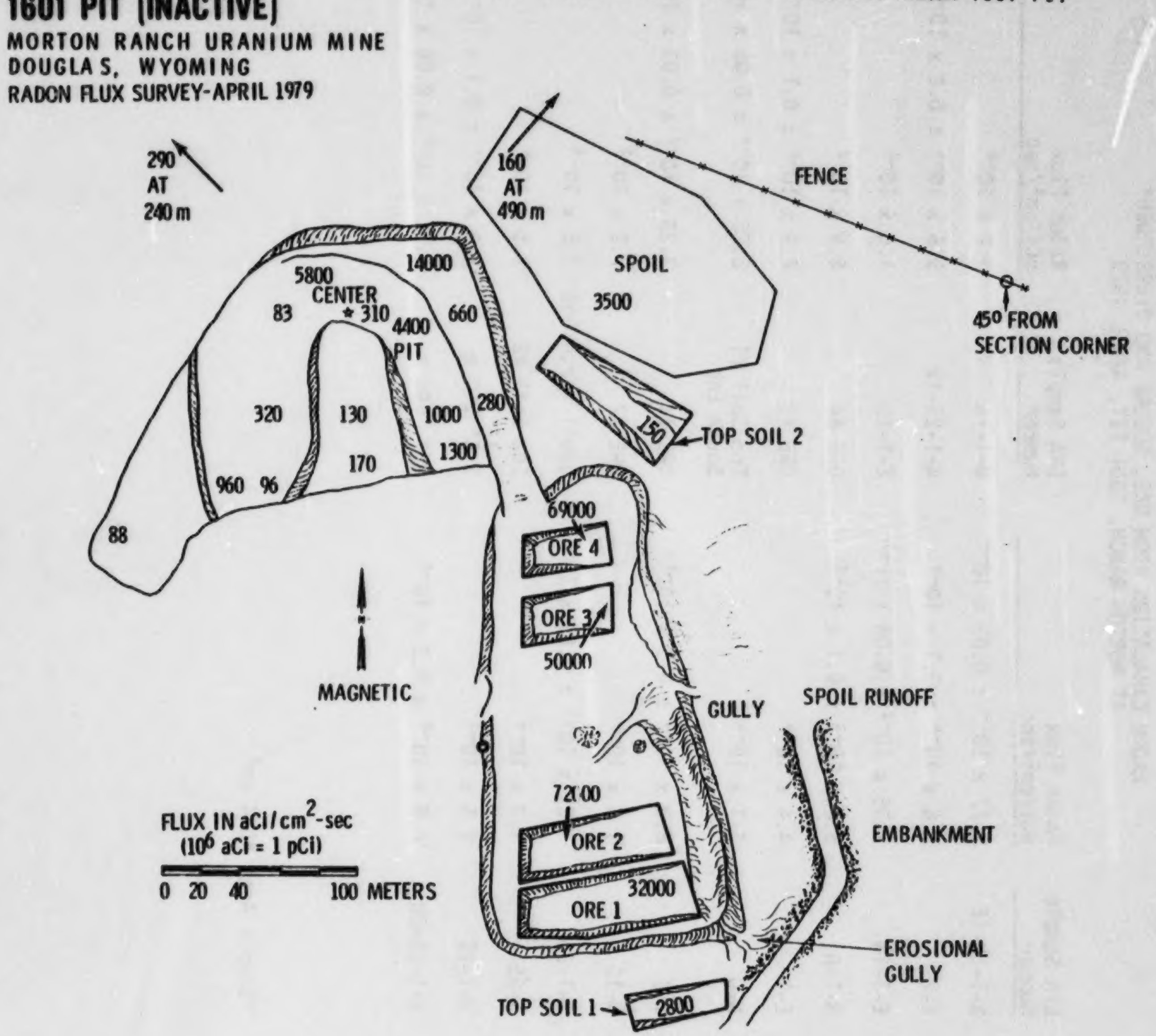

1601 PIT (INACTIVE)
MORTON RANCH URANIUM MINE
DOUGLAS, WYOMING
RADON FLUX SURVEY-APRIL 1979
290 AT 240 m
160 AT 490 m
FENCE
SPOIL
3500
45° FROM SECTION CORNER
TOP SOIL 2
150
14000
5800
CENTER
310
83
4400
PIT
660
320
130
1000
280
1300
170
960
96
88
MAGNETIC
69000
ORE 4
ORE 3
50000
GULLY
SPOIL RUNOFF
72000
ORE 2
EMBANKMENT
32000
ORE 1
EROSIONAL GULLY
TOP SOIL 1
2800
FLUX IN aCi/cm²-sec
(10⁶ aCi = 1 pCi)
0 20 40 100 METERS

TABLE 2

RADON EMISSION RATES FROM 1601 PIT AREA, MORTON RANCH, WY

(pCi/sec)

Location	Emission Rate
1601 pit (Mean of methods 1 and 2)	5.0×10^5
Topsoil #1 (south)	1.0×10^4
Topsoil #2 (north)	1.0×10^3
Topsoil southwest of pit (using flux from topsoil pile #2)	1.0×10^3
Spoil southwest of pit (using flux from north spoil pile)	1.5×10^4
Spoil (north)	4.2×10^5
Spoil beneath ore piles	5.9×10^5
Ore #1	4.5×10^5
Ore #2	8.7×10^5
Ore #3	2.7×10^5
Ore #4	3.5×10^5
Southeast embankment (using mean topsoil flux)	3.6×10^4
	Total = 3.5×10^6

TABLE 3

RADON FLUX MEASUREMENTS

(Charcoal Canister)

NEW MEXICO

Site	EPA Log No.	Area Description	ON Date Time	OFF Date Time	Rn Flux pCi/cm^2/Sec
San Mateo	91056	Leach pile	4/22 1118	4/25 1307	3.6×10^{-3}
	57	Leach pile	4/22 1123	4/25 1300	1.3×10^{-3}
	58	Leach pile	4/18 1635	4/25 1305	6.5×10^{-3}
	59	Dry pond	4/18 1645	4/25 1315	7.3×10^{-4}
	60	Waste pile	4/18 1655	4/25 1315	2.1×10^{-4}
	61	Waste pile (by shaft)	4/18 1703	4/25 1250	3.0×10^{-3}
	62	Waste pile	4/18 1708	4/25 1252	1.8×10^{-3}
	63	Dry wash	4/18 1710	4/25 1254	2.0×10^{-3}
	64*	Background	4/18 1728	4/25 1314	2.8×10^{-5}
	65	Waste pile	4/22 1237	4/25 1305	1.3×10^{-3}
	66	Waste pile	4/22 1245	4/25 1300	1.1×10^{-3}
	67	Waste pile	4/22 1250	4/25 1248	1.4×10^{-3}
	68	Waste pile	4/22 1300	4/25 1256	8.8×10^{-3}
	69	Waste pile	4/22 1318	4/25 1310	1.7×10^{-3}
	a	Waste pile	4/18 1523	5/3 0830	7.0×10^{-5}
	a	Waste pile	4/22 1056	5/3 0843	6.5×10^{-5}
	a	Waste pile	4/18 1515	5/3 0837	2.0×10^{-5}
	a	Waste pile	4/18 1518	5/2 0938	2.6×10^{-4}
Barbara J	90024	Waste pile	4/19 1340	4/25 1046	1.8×10^{-3}
	25	Waste pile	4/19 1342	4/25 1047	5.6×10^{-4}
	26	Waste pile	4/19 1344	4/25 1048	8.0×10^{-4}
	27	Waste pile	4/19 1346	4/25 1050	3.8×10^{-4}
	28	Background	4/19 1350	4/25 1056	8.1×10^{-5}
	29	Background	4/19 1356	4/25 1058	7.4×10^{-5}
	30	Waste pile	4/19 1358	4/25 1054	3.2×10^{-6}
	31	Waste pile	4/19 1400	4/25 1052	4.1×10^{-4}
	32	Small waste pile	4/19 1822	4/25 1101	7.9×10^{-4}

Table 3 (continued)

Radon Flux Measurements

Site	EPA Log No	Area Description	ON Date Time	OFF Date Time	Rn Flux pCi/cm^2/Sec
Poison Canyon Area 1	91033	Background	4/17 1415	4/25 1107	3.3×10^{-5}
	34	Floor pit 1	4/17 1408	4/25 1131	7.0×10^{-4}
	35	Waste pile 2	4/17 1400	4/25 1115	3.0×10^{-3}
	36	Waste pile 2	4/21 1213	4/25 1121	3.9×10^{-5}
	37	Waste pile 1	4/21 1138	4/25 1125	1.9×10^{-4}
	38	Waste pile 1	4/21 1055	4/25 1128	8.0×10^{-5}
	39	Bench pit 1	4/21 1237	4/25 1130	1.7×10^{-4}
	40	Terrace	4/21 1251	4/25 1134	1.2×10^{-4}
Poison Canyon Area 2	91041	Subore	4/17 1452	4/25 1146	1.5×10^{-4}
	42	Overburden	4/17 1445	4/25 1145	1.1×10^{-4}
	43	Pit floor	4/17 1440	4/25 1148	1.1×10^{-4}
	44	Pit floor	4/17 1437	4/25 1149	2.1×10^{-4}
	45	Subore	4/17 1430	4/25 1202	1.4×10^{-3}
	46	Background	4/21 1514	4/25 1215	1.0×10^{-4}
	47	Rim of pit	4/21 1558	4/25 1213	1.2×10^{-4}
	48	Subore	4/21 1617	4/25 1201	1.0×10^{-3}
	49	Overburden	4/21 1625	4/25 1204	2.6×10^{-3}
	50	Overburden	4/21 1640	4/25 1157	6.3×10^{-4}
	51	Subore	4/21 1650	4/25 1156	3.3×10^{-4}
	52	Overburden	4/21 1700	4/25 1151	1.4×10^{-4}
	53	Subore	4/21 1705	4/25 1852	1.1×10^{-3}
Poison Canyon Area 3	90054		4/17 1510	4/24 1513	1.4×10^{-3}
	55		4/17 1510	4/24 1505	7.4×10^{-4}

(*) environmental background sample

(a) analyzed by BNL

FIGURE 3

SAN MATEO MINE NEW MEXICO

RADON FLUX SURVEY-APRIL 1979

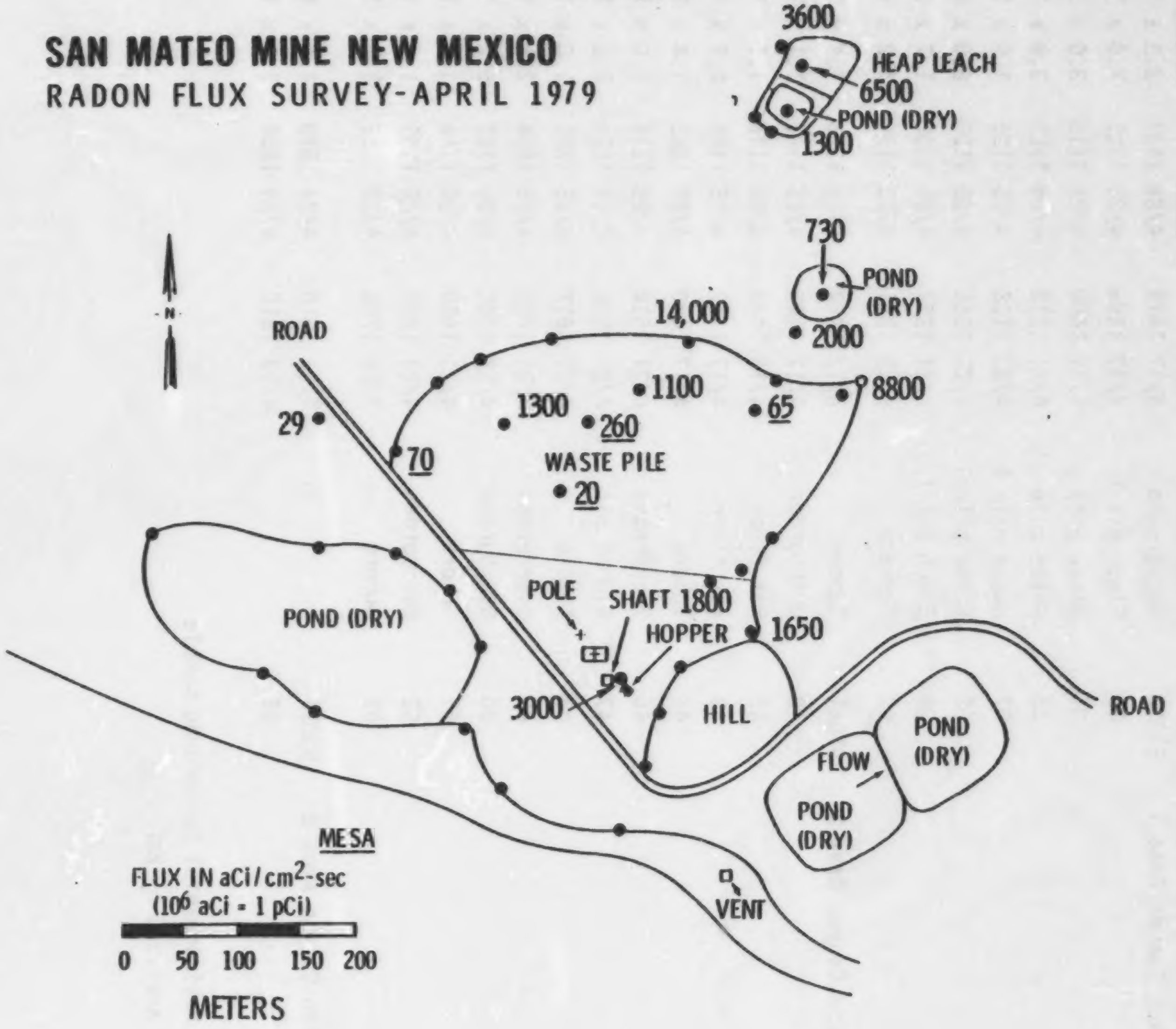
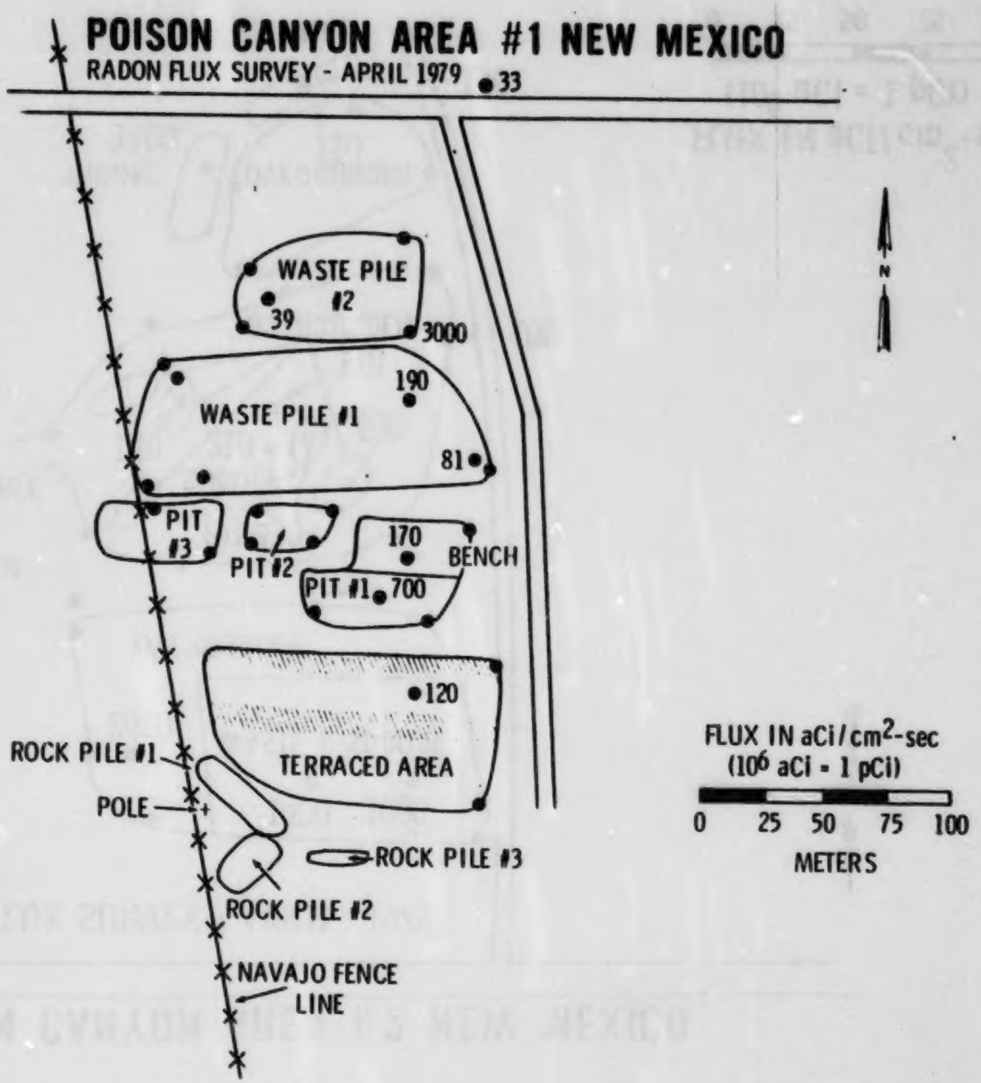

3600
HEAP LEACH
6500
POND (DRY)
1300
730
POND (DRY)
2000
8800
14,000
1100
65
1300
260
WASTE PILE
20
29
70
ROAD
N
POND (DRY)
POLE
SHAFT
1800
HOPPER
1650
3000
HILL
ROAD
POND (DRY)
FLOW
POND (DRY)
MESA
VENT
FLUX IN aCi/cm2-sec
(106 aCi = 1 pCi)
0 50 100 150 200
METERS

FIGURE 4



POISON CANYON AREA #1 NEW MEXICO

RADON FLUX SURVEY - APRIL 1979

33
WASTE PILE #2
39
3000
WASTE PILE #1
190
81
PIT #3
PIT #2
170
BENCH
PIT #1
700
120
TERRACED AREA
ROCK PILE #1
POLE
ROCK PILE #3
ROCK PILE #2
NAVAJO FENCE LINE
N
FLUX IN aCi/cm²-sec
(10⁶ aCi = 1 pCi)
0
25
50
75
100
METERS

FIGURE 5

POISON CANYON AREA #2 NEW MEXICO

RADON FLUX SURVEY - APRIL 1979

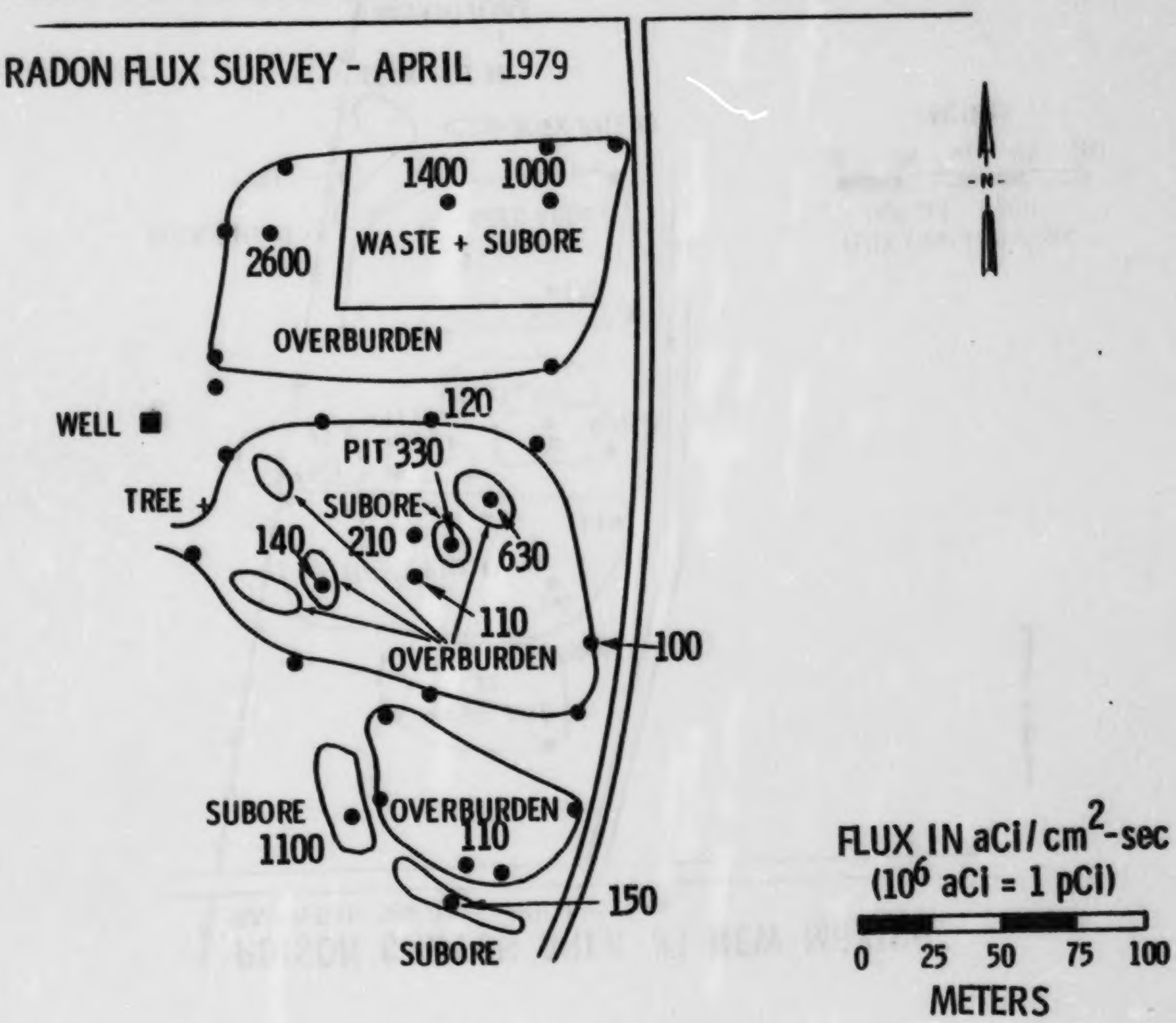
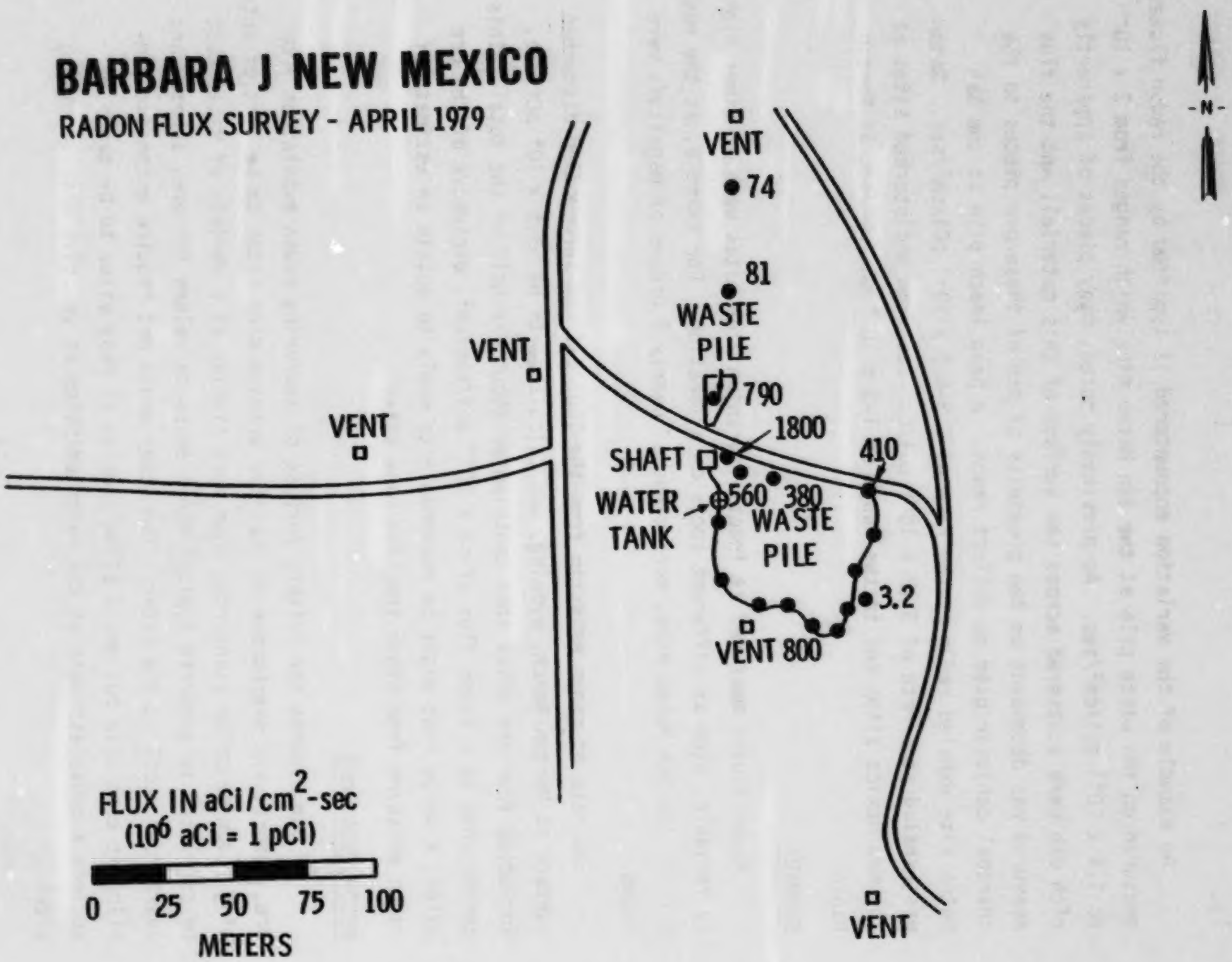

1400
1000
WASTE + SUBORE
2600
OVERBURDEN
120
WELL
PIT 330
TREE
SUBORE
140
210
630
110
OVERBURDEN
100
SUBORE
1100
OVERBURDEN
110
150
SUBORE
N
FLUX IN aCi/cm^2-sec
(10^6 aCi = 1 pCi)
0
25
50
75
100
METERS

FIGURE 6



BARBARA J NEW MEXICO

RADON FLUX SURVEY - APRIL 1979

-N-
VENT
74
81
WASTE PILE
790
1800
VENT
VENT
SHAFT
WATER TANK
560
380
WASTE PILE
410
3.2
VENT 800
VENT
FLUX IN aCi/cm²-sec
(10⁶ aCi = 1 pCi)
0
25
50
75
100
METERS

been designated subore and two subore piles are more likely overburden material. Radon exhalation of subore and overburden at the Poison Canyon site was in the range of ~1-3 x 10^{-3} pCi/cm^2/sec and 3 x 10^{-4} pCi/cm^2/sec, respectively.

An example of the variation encountered is typified by the radon fluxes measured on the waste pile at the San Mateo mine which ranged from 2 x 10^{-5} to 1.4 x 10^{-2} pCi/cm^2/sec. As previously noted, many pieces of apparently rich ore were scattered across the surface of this material, and the flux measured was dependent on the proximity of one of these ore pieces to the charcoal canister used to collect radon. A heap leach pile at the San Mateo site exhaled radon at the rate of 1.3-6.5 x 10^{-3} pCi/cm^2/sec. Radon was exhaled at a rate of 3-12 x 10^{-5} pCi/cm^2/sec from undisturbed sites at the New Mexico sites and in the range of 1-3 x 10^{-4} pCi/cm^2/sec at Morton Ranch.

SUMMARY

Radon fluxes measured at inactive uranium mine sites were at times highly variable, even at different spots on a location. For example, at the waste pile at the San Mateo mine, variations of nearly 3 orders of magnitude were found.

The rate of radon emission from the 1601 pit and surrounding disturbed surface at Morton Ranch, Wyoming, was calculated to be ~3.5 x 10^{6} pCi/sec, including four ore piles that contributed about one-half of the total. This corresponds to a radon flux of ~3 x 10^{-3} pCi/sec/cm^2, exclusive of the ore piles, a value that might be reasonable to apply to obtain an estimate of radon emission from other inactive mine sites.

RECOMMENDATIONS

If one assumes the primary purpose of measuring radon exhalation from ore, subore, and overburden in inactive uranium mine sites to be that of setting radon emission standards, then more studies at a variety of sites must be completed to generate typical radon emission values for ore, subore, and overburden spoil at the sites. The study would not require extensive sampling at each site but would allow samples at many sites to be taken to achieve a gross estimate of the radon emission at inactive uranium mining sites.

TASK 8
SITE MAPPING

INTRODUCTION

Site maps have been developed for the Barbara J, Poison Canyon drainage, Poison Canyon Area 1, Poison Canyon Area 2, San Mateo, and Mesa Top mines in the State of New Mexico; the Morton Ranch mine near Douglas, Wyoming; and uranium mines in the Uravan and Boulder areas of Colorado. A general description has been prepared for each site, providing detail relevant to pit size, waste and subore areas, and top soil piles which are associated with the mined areas. These measurements were done using a variety of measurement techniques. Theodolites or other accurate survey instrumentation were not available at any of the sites. All data were calculated using standard trigonometric functions, applying data obtained with range measuring devices such as a rangematic or actual distances measured by tape measures. A variety of techniques were used to determine inclinations and angles. Data estimates for pit size, waste pile volume, and character as well as environmental comments are summarized in Table 1.

DISCUSSION

New Mexico

Barbara J Mine

The Barbara J mine, a small mine located in New Mexico in the Poison Canyon area, is an inactive mine that was mined in the 1950's and 1960's. It has four open vents and one sealed vent. The shaft has been covered with a quarter-inch steel plate which has several perforations and a large pipe extending vertically from it. The edge of the plate has been pried up at one corner to a 40 cm height. The vents are cased at the surface. They are generally 30 cm in diameter, and are covered with inverted metal buckets. Three of these buckets have been pierced with small holes at the present time and one of them fits quite loosely on the vent. One vent is covered by a small wooden plank which leaves a small gap around its edges. There are two waste piles at the site. One is an extremely small pile (230 cubic meters) and the other is a somewhat larger pile (3280 cubic meters). (See Figure 1.) No water drainage system connects this site to other waterways.

TABLE 1

Physical Parameters For the Inactive Mines Studied In Wyoming, New Mexico and Colorado

State	Mine	Mine Type†	# of Pits	Total Pit/Mine Volume (M^3)	# of‡ Vents	# of Waste Piles	Total Ore (M^3)	Total Subore (M^3)	Total Overburden (M^3)	Environmental Comments
New Mexico	Barbara J	U			4 ov 1 cv	2			3,510	No water drainage to waterways.
	Poison Canyon #1	O	3	16,100		2			27,900	A terraced overburden existed with 5550 M^3. Rock piles exist of 990 M^3. Many gullies to a main drainage.
	Poison Canyon #2	O	1	84,000		3+		4,200	41,000	Many small pits, has gullies to main drainage, a well, and a pond.
	San Mateo	U			>1	>1	**	**	310,000	Contains heap leach ponds; has significant runoff and drainage. Deep gullies lead to San Mateo Creek.
	Mesa Top	U			>10					Connected to many active and inactive mines.
Wyoming	Morton Ranch	O	1	172,000		>10	7,300		164,000	Contains drainage to S. Box Creek.
Colorado	Uravan #1	U			>1	>1			14,000	Wind and water erosion evident.
	Uravan #2	U			>1	1			1,200	A Rim mine, wind and water erosion evident.
	Uravan #3	U			>1	>2			40,000	
	Uravan #4	U			>1	1			6,000	A rim mine, waste eroded to San Miguel River.
	Uravan #5	U			>1	2			75,000	Water and wind erosion evident.
	Uravan #6	U			>1	1			45,000	Water and wind erosion evident.
	Boulder #7	U			>1	1			35	Erosion evident.
	Jamestown #8	U			>1	1			1,600	Fluorspar mine, water erosion.
	Jamestown #9	U			>1	1			450	
	Jamestown #10	U			>1	>1			150	Water and wind erosion.

†U = Underground, O = Open pit
‡ov = Open Vents, cv = closed vents
** = Present owner did not allow a survey

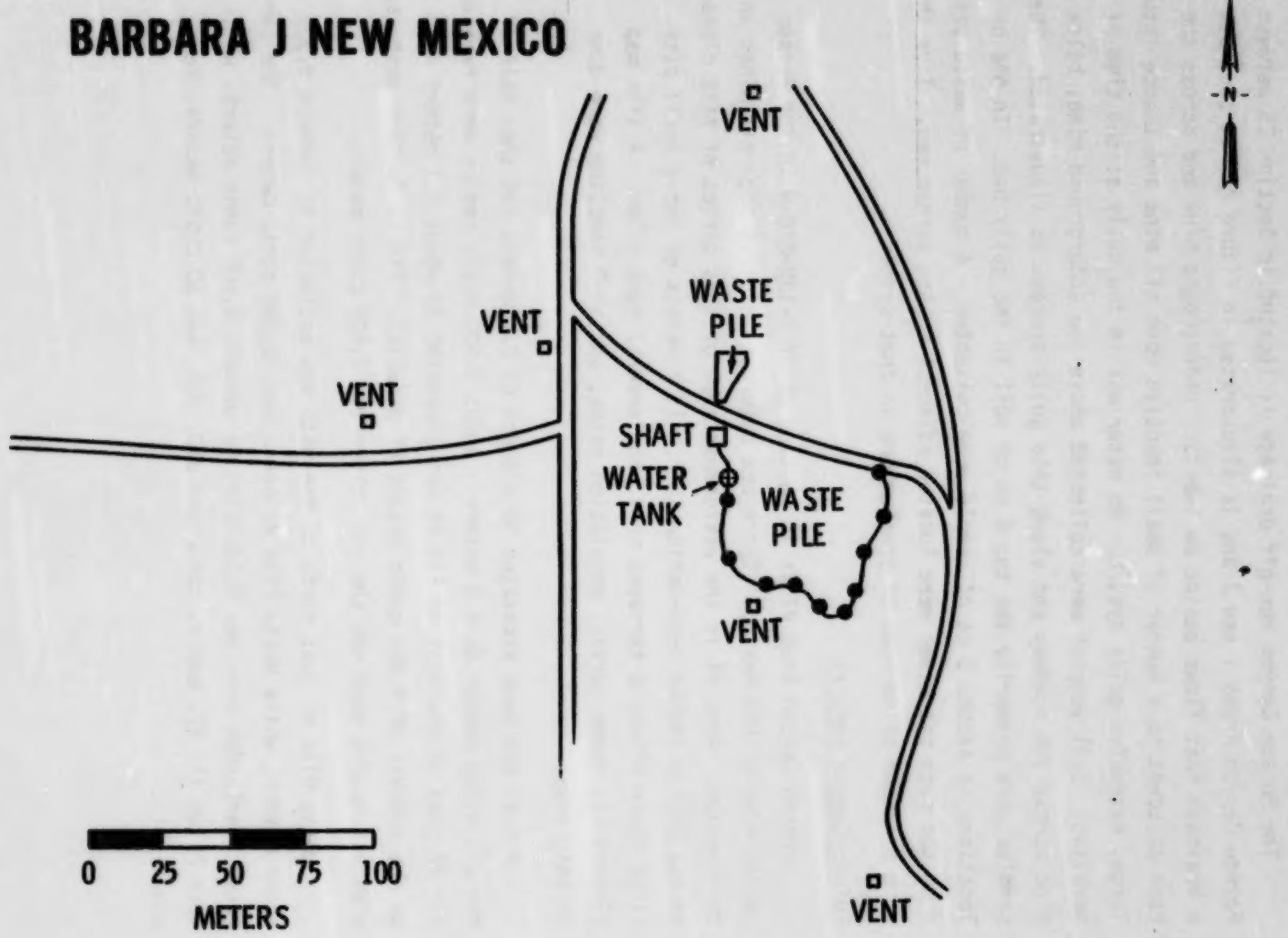

BARBARA J NEW MEXICO
N
VENT
VENT
VENT
WASTE PILE
SHAFT
WATER TANK
WASTE PILE
VENT
VENT
0
25
50
75
100
METERS

Figure 1

Poison Canyon

The Poison Canyon run-off drainage is located in Section 25 between Poison Canyon Areas 1 and 2 and is illustrated in Figure 2. It consists of a drainage that flows beside an inactive underground mine and across the road adjacent to a number of small inactive open pit mine and thence into a large, extensive gully system. No water was in the gully at the time of sampling. Soil samples were collected above the underground mine, below the mine across the roadway and along this gully system, as illustrated. These samples were primarily the top 5 cm of soil in the gully bed. In one or two locations, a second 5 cm of sample were collected. A number of waste piles from the open pit mines were located adjacent to the stream bed. Thus there were a number of sources of uranium ore in that system.

Poison Canyon Area #1

Poison Canyon Area #1 is in Section 25 of T-13N-R10-W in the Poison Canyon area of New Mexico. There are numerous inactive open pit mines in this region. Area #1 is the westermost area of this series of pits closest to the Navajo Indian reservation land. It consists of three small pits, two large waste piles, a terraced area, and several rock piles. A site map (Figure 3), gamma survey, exhalation rates, and soil sampling were done in this area.

Pit #1 has been excavated to a depth of 2.4 meters and then half of the pit mined deeper to 4.3 meters. About 3,900 cubic meters were removed. Pit #2 just to the west of Pit #1 was excavated to about 9.1 meters deep by the removal of 4,600 cubic meters of material. Pit #3 further west was also 9.1 meters deep and the pit volume was 7,600 cubic meters.

Waste Pile #1 just north of the pits was estimated to contain 9,900 cubic meters, while Waste Pile #2 contained 18,000 cubic meters. The terraced overburden area was calculated to contain 5,500 cubic meters, while Rock Piles #1, #2, and #3 contained 630, 300, and 60 cubic meters, respectively.

POISON CANYON NEW MEXICO
MINE DRAINAGE SYSTEM - SECTION 25

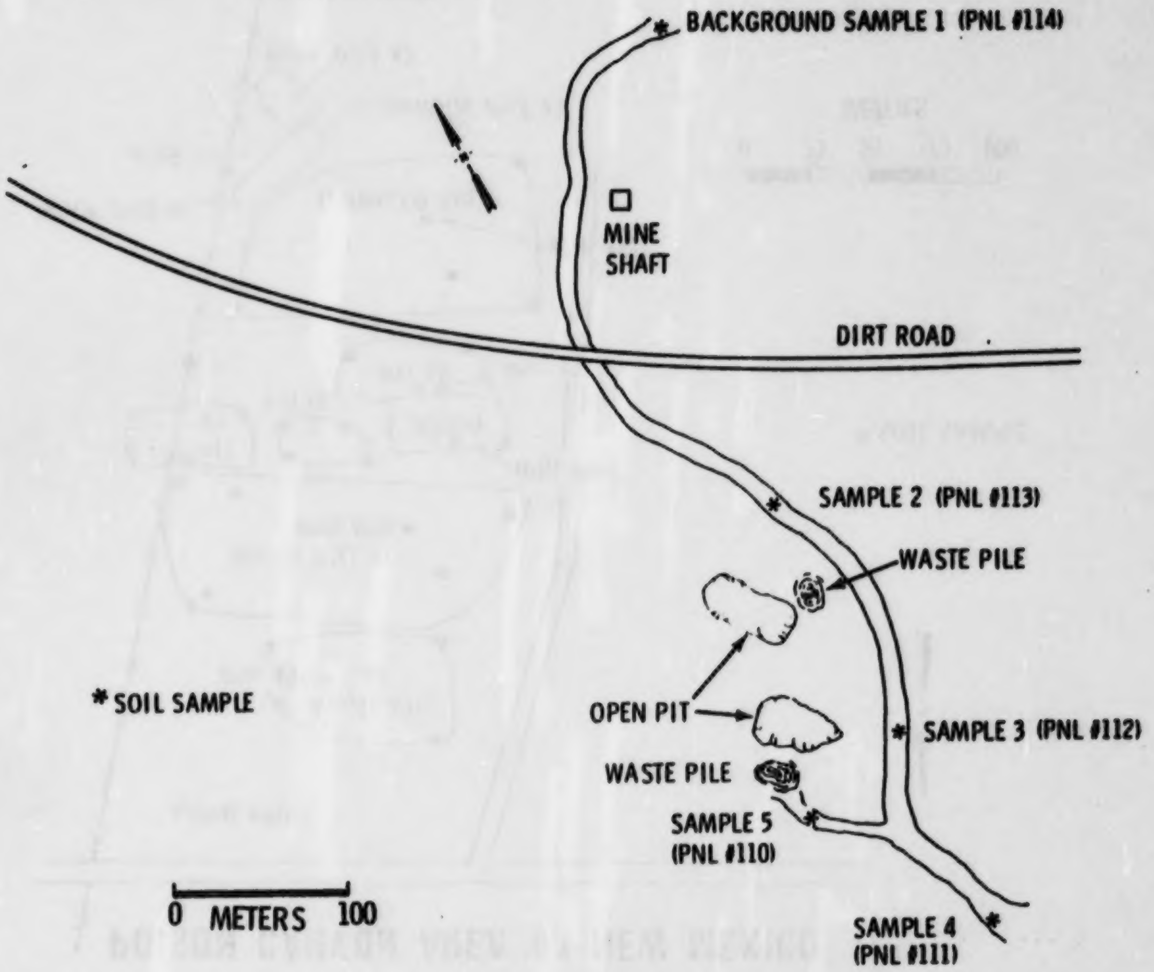

BACKGROUND SAMPLE 1 (PNL #114)
MINE SHAFT
DIRT ROAD
SAMPLE 2 (PNL #113)
WASTE PILE
OPEN PIT
SAMPLE 3 (PNL #112)
WASTE PILE
SAMPLE 5 (PNL #110)
SAMPLE 4 (PNL #111)
* SOIL SAMPLE
0 METERS 100

Figure 2

POISON CANYON AREA #1 NEW MEXICO

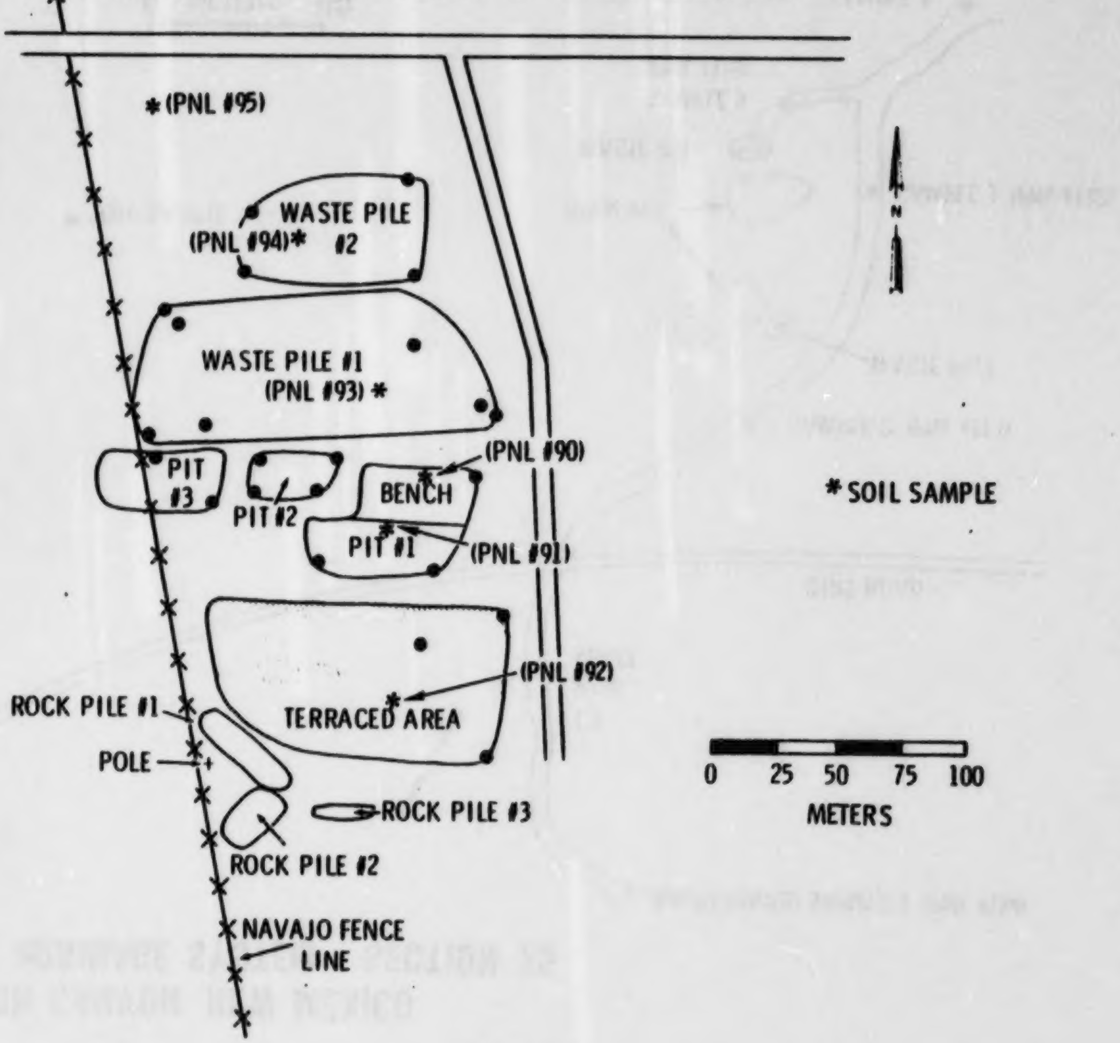

* (PNL #95)
WASTE PILE #2
(PNL #94)*
WASTE PILE #1
(PNL #93) *
PIT #3
PIT #2
BENCH
(PNL #90)
PIT #1
(PNL #91)
(PNL #92)
TERRACED AREA
ROCK PILE #1
POLE
ROCK PILE #3
ROCK PILE #2
NAVAJO FENCE LINE
N
* SOIL SAMPLE
0
25
50
75
100
METERS

Figure 3

Poison Canyon Area #2

Poison Canyon Area #2 is located sotheast of Poison Canyon Area #1 in the same section of land. It is a single large open pit which has a large overburden pile on the north side and a smaller overburden pile on the south side. Farther south of the smaller overburden pile are small piles which appear to be ore or subore. On top of the northern overburden pile, waste and subore are stacked. The waste and subore can be distinguished from overburden by the color. Overburden in this area tends to be reddish brown while waste and subore are grey colored. The pit has several apparent piles of subore remaining in it. These may consist of unexcavated areas in the pit, since the ore and subore constitute a layer between the brown overburden and the brown base material in the pit. A site map (Figure 4) and gamma surveys were made here, and samples of the overburden, waste and subore and samples from the apparent ore piles were collected from this area. In addition, samples of the red earth were collected at the bottom of the pit and the pit rim. Background samples were collected from an adjacent area. Radon exhalation rates were measured on the waste pile and overburden piles. A water sample was collected at the well in Area 2 of Poison Canyon. Another water sample was collected east of Area 2 in an open pond which was partially filled with water. This was designated as Area 3.

The pit which was excavated to a depth of about 10 meters left a hole of 84,000 cubic meters. The northern overburden pile underlying the waste and subore contained 28,000 cubic meters, while the volume of the south overburden pile was estimated at 13,000 cubic meters. The waste and subore on top of the north overburden pile measured 3,900 cubic meters, and the two small subore piles south of the pit contained 220 and 85 cubic meters of material.

San Mateo Mine

The San Mateo mine, located near San Mateo, New Mexico, is a large inactive underground uranium mine of the vertical shaft type. Significant features include a very large waste pile (3.1×10^5 cubic meters) which extends the mesa on which the shaft is located by about 200 meters to the north.

POISON CANYON AREA #2 NEW MEXICO

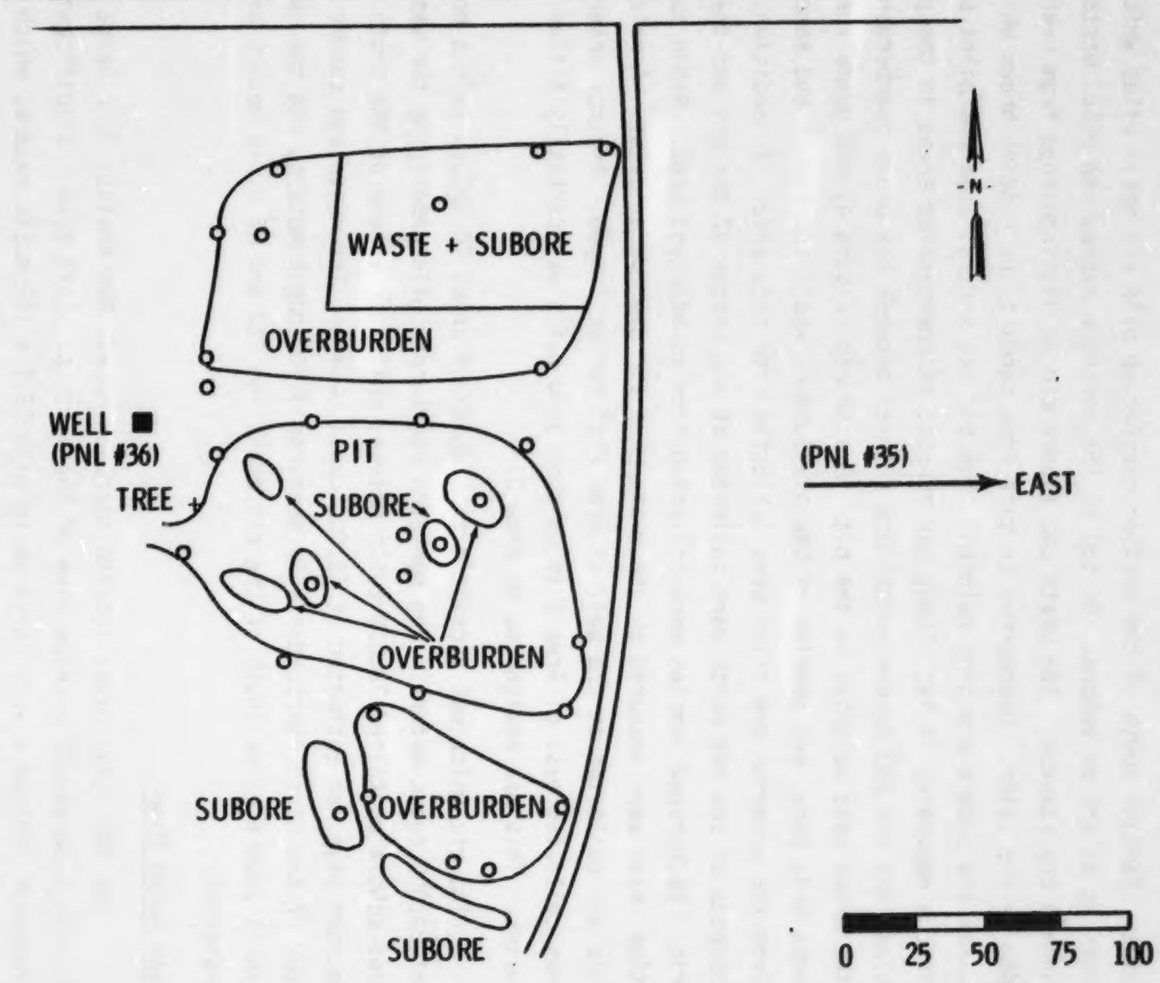

N
WASTE + SUBORE
OVERBURDEN
WELL ■
(PNL #36)
PIT
TREE +
SUBORE
OVERBURDEN
(PNL #35)
EAST
SUBORE
OVERBURDEN
SUBORE
0 25 50 75 100
METERS

Figure 4

The pile extends from grade level at the mesa to a height of approximately 12 meters at its outside edge. A system of heap leach ponds is located between the mesa shaft area and the highway. Several dry ponds surround the shaft area. The mine itself is not amenable to measurement of radon emissions from underground because it is believed to be flooded. This mine area has a very significant run-off and drainage which is indicated on the site maps (Figures 5 and 6). A system of deep gullies runs down the fields from the mining area, eventually leading to the San Mateo Creek. This mine is isolated by a large ranch and the previous mining operators no longer have access to clean up the area. It is reported that the uranium content of aboveground waste piles and heap leach piles are currently economically mineable. Radon exhalation rates, soil samples, and gamma surveys were taken at this site. In addition, extensive gamma surveys and soil sampling were done on the gully system leading from the site to examine the run-off characteristics from the waste pile and the heap leach pond. Background soil samples were collected beside the road leading into the area. And water was also collected from the San Mateo Creek at the Marquez ranch, which is about 3 km downstream from the mine drainage system to San Mateo Creek. In addition, a sediment sample was collected from the San Mateo Creek bed. A second sediment and water sample was collected approximately 2 km upstream from the intersection of the run-off gully from the mine and the San Mateo Creek.

Mesa Top Area

The Mesa Top area in New Mexico is located on the top of the Mesa Montoza which lies between the Poison Canyon area and the Ambrosia Lake area. This mine was an extensive underground mine judging from the number of vents located at the surface. The ventilation system consisted of numerous 30 cm diameter uncased holes which were found in the area. The single large 1-meter diameter escape vent was adjacent to the shaft at a distance of about 110 meters. This vent was tightly sealed with the exception of the small cracks around an access door which was cut into its side. The shaft area was surrounded by a small wire fence at a distance of about 2 meters from the shaft. The shaft itself had been covered with planking which at the present time is in a rotting state with moss growing on it and appears to be in imminent danger of collapse. The mine is connected to several other underground mines in the area.

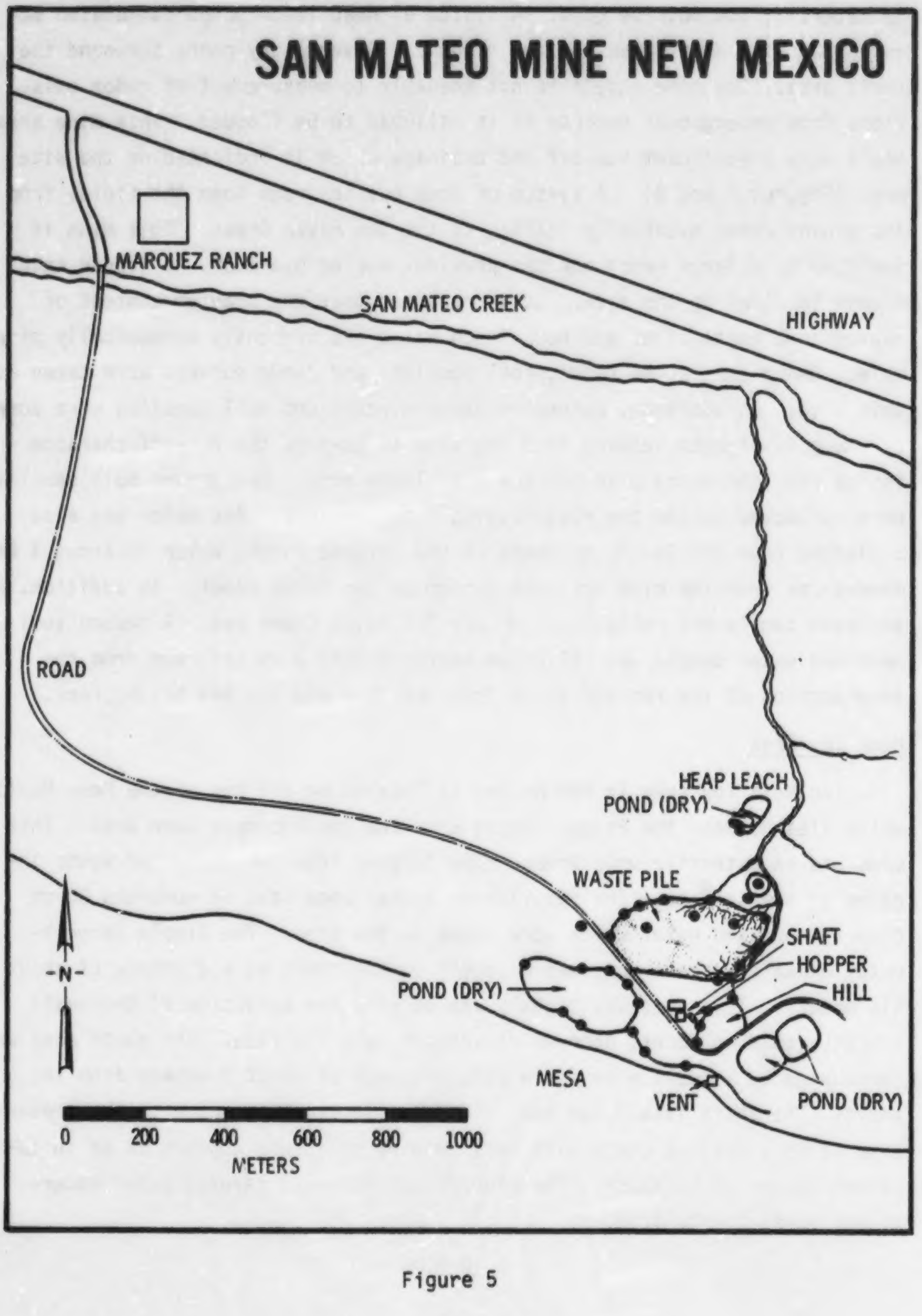
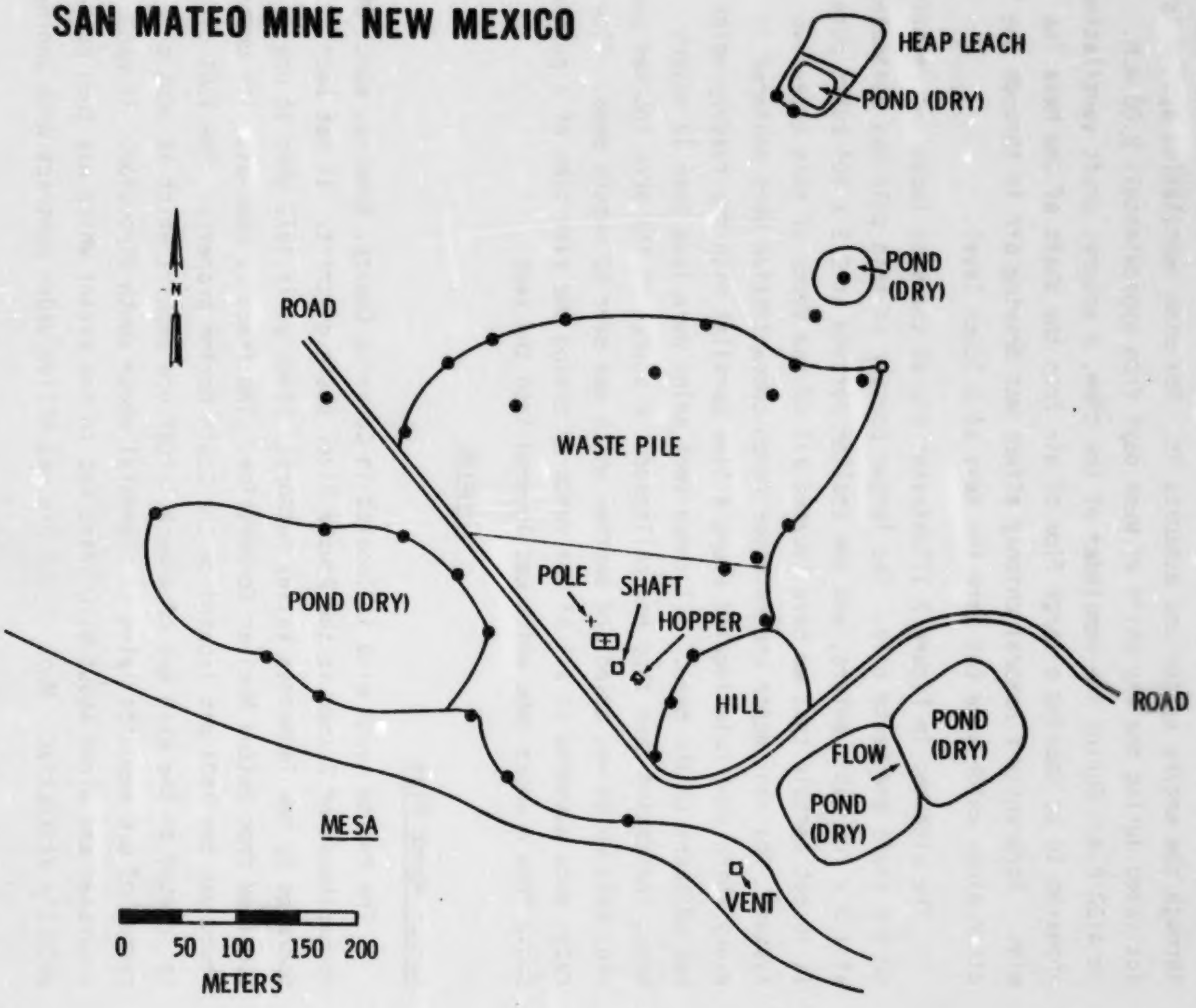

SAN MATEO MINE NEW MEXICO
MARQUEZ RANCH
SAN MATEO CREEK
HIGHWAY
ROAD
HEAP LEACH
POND (DRY)
WASTE PILE
SHAFT
HOPPER
HILL
POND (DRY)
MESA
VENT
POND (DRY)
N
0
200
400
600
800
1000
METERS

Figure 5


SAN MATEO MINE NEW MEXICO

HEAP LEACH
POND (DRY)
POND (DRY)
N
ROAD
WASTE PILE
POLE
SHAFT
HOPPER
HILL
ROAD
POND (DRY)
FLOW
POND (DRY)
POND (DRY)
MESA
VENT
0 50 100 150 200
METERS

Figure 6

One of the connected mines is the Malpais mine. This in turn connects to the Dog, the Flea, the Doris 2, and the Doris 1. The Doris 1 and 2 are being actively mined and use a ventilation fan located in the Dog mine. When this fan is activated, it draws air from the Mesa Top mine openings through the entire system and exhausts it. The mine ventilation system is activated during the day shift of week days from approximately 8:00 A.M. to 4:00 P.M. During the remainder of the time, a natural draft ventilation appeared to be causing a large flow of air from the shaft of the Mesa Top mine. Apparently a natural chimney effect was drawing air in through the other mines which were cut into the Mesa at a lower level.

The site map in Figure 7 illustrates six of the vent locations relative to the shaft and waste pile. The larger portion of this pile was estimated at 1.3 x 10^4 cubic meters, and the smaller portion at 2.2 x 10^3 cubic meters. It is not certain that we have located all of the vents of this extensive system. The vent depth and interior radon concentration were measured in every third vent hole located along a line parallel with the roadway which was adjacent to the mine. All these vent holes were less than 12 meters deep, indicating that they had collapsed. A search of the area located one vent hole which was cased and another which was over 30 meters deep. Flow rates were measured at all of the vents by timing the rise time of a puff of smoke from a smoke tube which was lowered into the vent.

Wyoming

Morton Ranch Mine

The Morton Ranch mine is located in Converse County, Wyoming, about 80 km northeast of Casper in the Powder River Basin district. It has been operated by the Tennessee Valley Authority since early 1979 when it was acquired from United Nuclear Corporation. The inactive open-pit site under study was the 1601 pit located on the South Morton property. The 1601 pit is located on the east end of a much larger ore deposit which is part of a system of ore deposits lying in a general north-south direction. It was excavated and mined about 8-10 years ago to the extent which was then economically attractive. Much of the ore was milled under contract with another

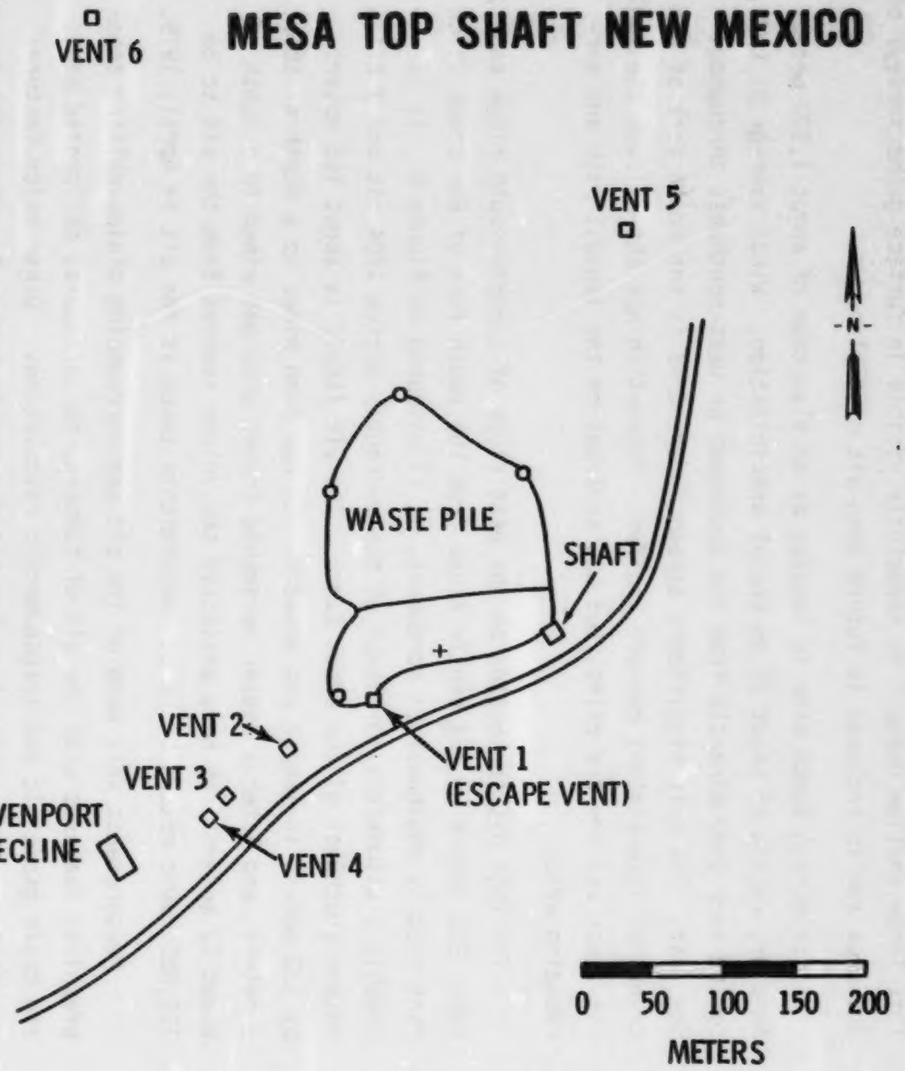

MESA TOP SHAFT NEW MEXICO
VENT 6
VENT 5
N
WASTE PILE
SHAFT
VENT 1
(ESCAPE VENT)
VENT 2
VENT 3
VENT 4
DAVENPORT
DECLINE
0
50
100
150
200
METERS

Figure 7

company, although four large ore or subore piles were kept at the side of the pit for possible future use. The pit appears to have been inactive since its original mining period.

Numerous veins of yellow high-grade ore are visible in the pit walls. Natural outcroppings of ore are also visible to the south of the 1601 pit, indicating the large ore deposit in that area to be very near to the surface. This large shallow deposit is expectedly visible in surface gamma surveys of the area and is included in future open-pit mine plans.

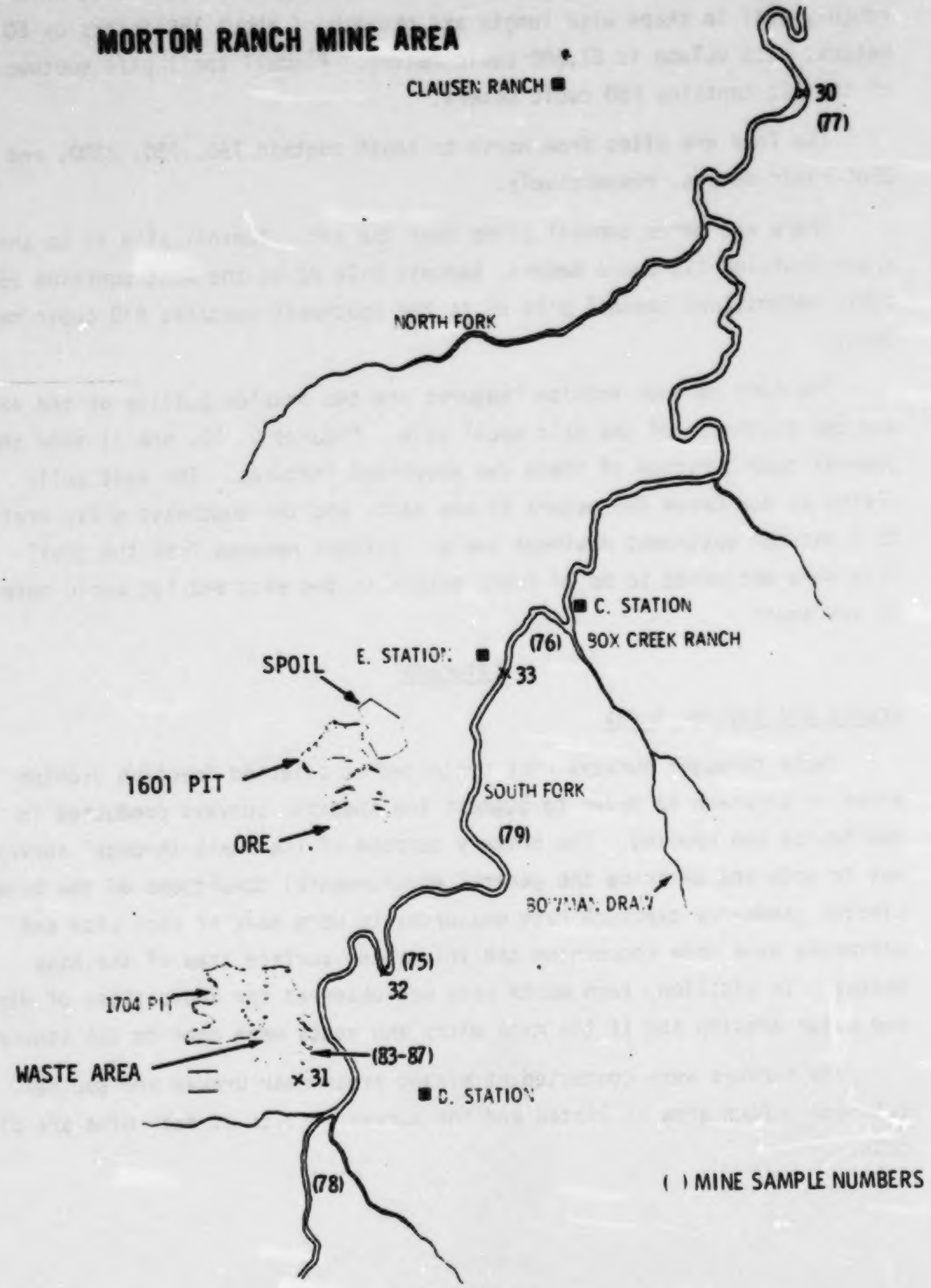
The Morton Ranch mine is located at an elevation of about 1,500 meters in a dry region of about 28 cm annual precipitation. Winds average 21 km/h, coming very predominantly from the southwest or west-southwest throughout the year. The only significant stream in the area is the south fork of Box Creek, an intermittent run-off aquifer. Vegetation was absent from the 1601 pit floor and the ore piles, but was apparent on the topsoil pile and surrounding areas.

The 1601 pit is located on the east slope of a north-south ridge and is about 820 meters up the gentle slope from the south fork of Box Creek which runs roughly southwest to northeast, as illustrated in Figure 8. It is roughly 2 kilometers northeast of the currently active 1704 pit and 3 kilometers southwest of Box Creek Ranch. The pit itself is about 165 meters by 130 meters in length and breadth. It has been mined to a depth of about 6 meters, and later a deeper horseshoe-shaped area was mined to a depth of about 12 meters. We have estimated the volume removed from the pit to be 172,000 cubic meters based on measurements taken at the pit in April, 1979.

Measurements were made of the pit and surrounding mining-related topographical features with the aid of compass, rangefinders, calibrated pace, and basic geometric and trigonometric calculations. Other major features and their relative dimensions are illustrated in Figure 9. The major deposit of spoil from the pit is to the southwest of the pit and underlies the four ore piles. This spoil pile measures approximately 80 meters by 210 meters and contains about 102,000 cubic meters of material.

Figure 8

MORTON RANCH MINE AREA


CLAUSEN RANCH
30
(77)
NORTH FORK
C. STATION
(76)
BOX CREEK RANCH
E. STATION
33
SPOIL
1601 PIT
ORE
SOUTH FORK
(79)
BOWMAN DRAW
(75)
32
1704 PIT
WASTE AREA
(83-87)
31
D. STATION
(78)
( ) MINE SAMPLE NUMBERS

The next largest feature is the spoil pile to the northeast, which is roughly oval in shape with length and breadth of about 150 meters by 60 meters. Its volume is 61,600 cubic meters. A small spoil pile southwest of the pit contains 660 cubic meters.

The four ore piles from north to south contain 760, 730, 2300, and 3500 cubic meters, respectively.

There are three topsoil piles near the pit. Topsoil pile #1 to the south contains 270 cubic meters, topsoil pile #2 to the west contains 980 cubic meters, and topsoil pile #3 to the southwest contains 810 cubic meters.

The most obvious erosion features are two erosion gullies on the east and the southeast of the main spoil pile. Figures 9, 10, and 11 show the general configuration of these two erosional features. The east gully drains to Box Creek 820 meters to the east, and the southeast gully drains to a natural east-west drainage swale. Volumes removed from the spoil pile were estimated to be 34 cubic meters to the east and 130 cubic meters to the south.

Colorado

Uravan and Boulder Areas

"Walk through" surveys were conducted at selected inactive uranium mines in Colorado in order to augment the specific surveys conducted in New Mexico and Wyoming. The primary purpose of the "walk through" surveys was to note and describe the general environmental conditions of the mines. Limited gamma-ray exposure rate measurements were made at each site and estimates were made concerning the volume and surface area of the mine wastes. In addition, each waste area was observed for indications of wind and water erosion and if the mine entry and vents were open to the atmosphere.

The surveys were conducted at mining areas near Uravan and Boulder, Colorado. Each area is listed and the survey results at each mine are discussed.

1601 PIT MORTON RANCH WYOMING

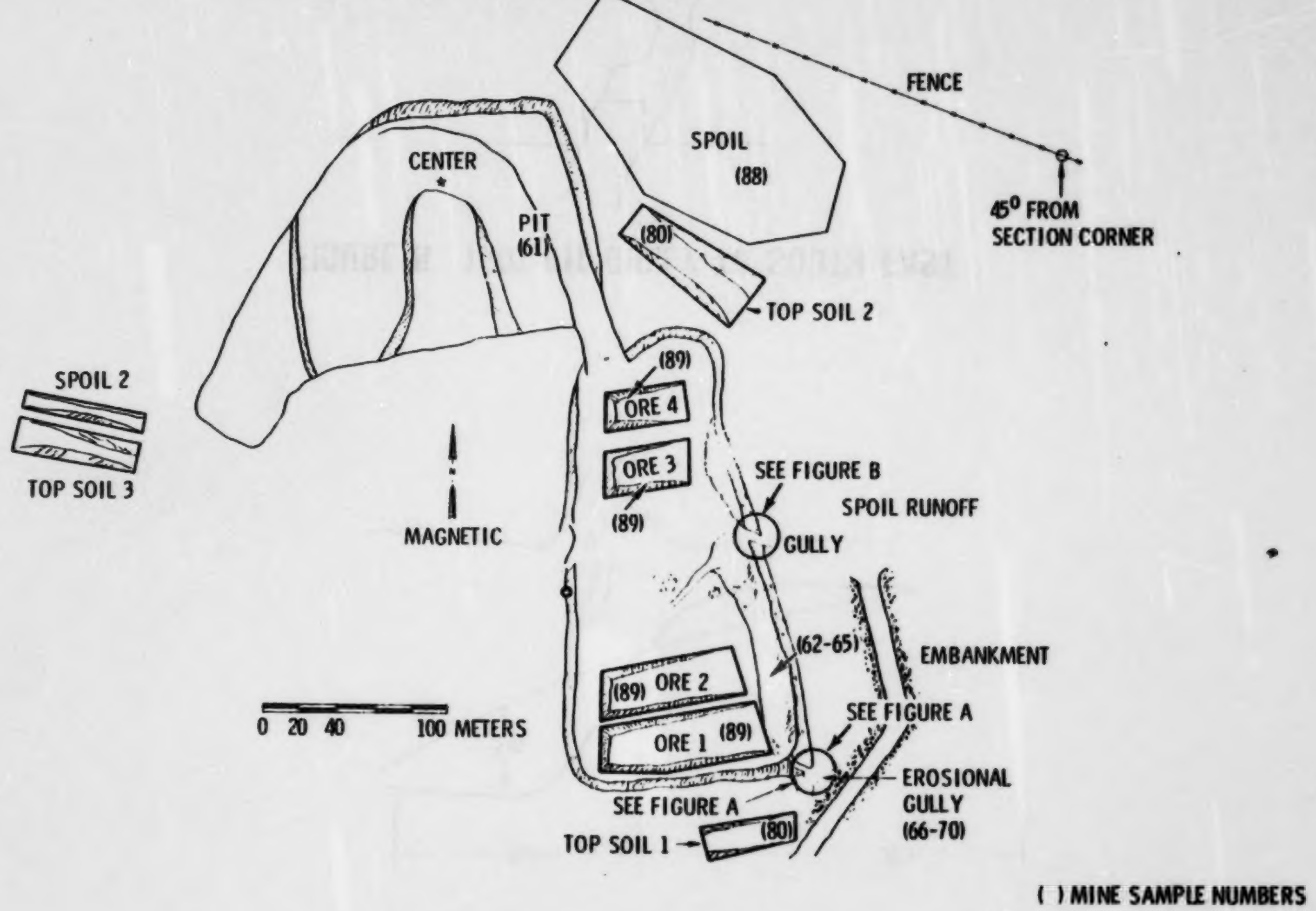

FENCE
SPOIL
(88)
45° FROM
SECTION CORNER
CENTER
PIT
(61)
(80)
TOP SOIL 2
(89)
ORE 4
ORE 3
(89)
SEE FIGURE B
SPOIL RUNOFF
GULLY
SPOIL 2
TOP SOIL 3
MAGNETIC
(62-65)
EMBANKMENT
(89) ORE 2
ORE 1 (89)
SEE FIGURE A
0 20 40 100 METERS
EROSIONAL
GULLY
(66-70)
SEE FIGURE A
TOP SOIL 1
(80)
( ) MINE SAMPLE NUMBERS

Figure 9

FIGURE A 1601 PIT GULLY TO EAST

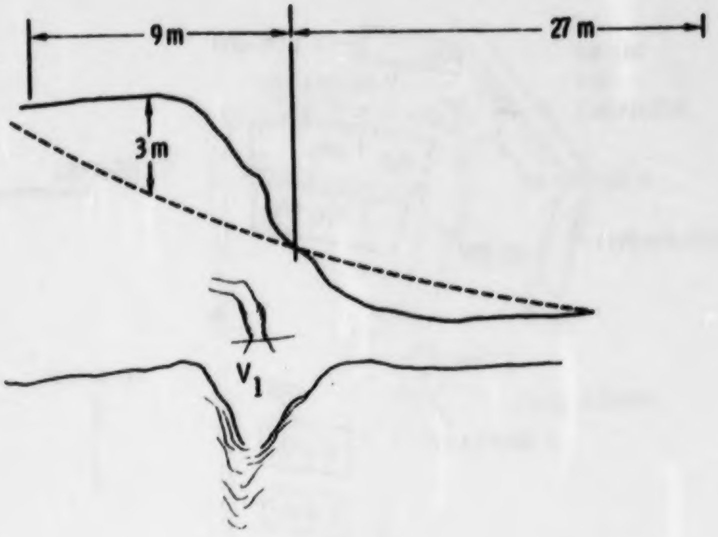


FIGURE B 1601 PIT GULLY TO SOUTH EAST

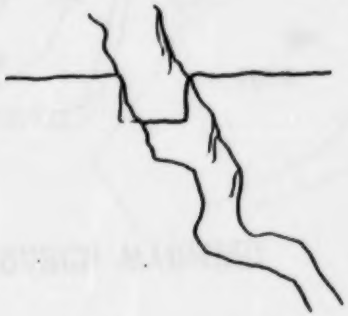


Figure 10

EROSION PATHWAY FROM 1601 TO SOUTH FORK BOX CREEK

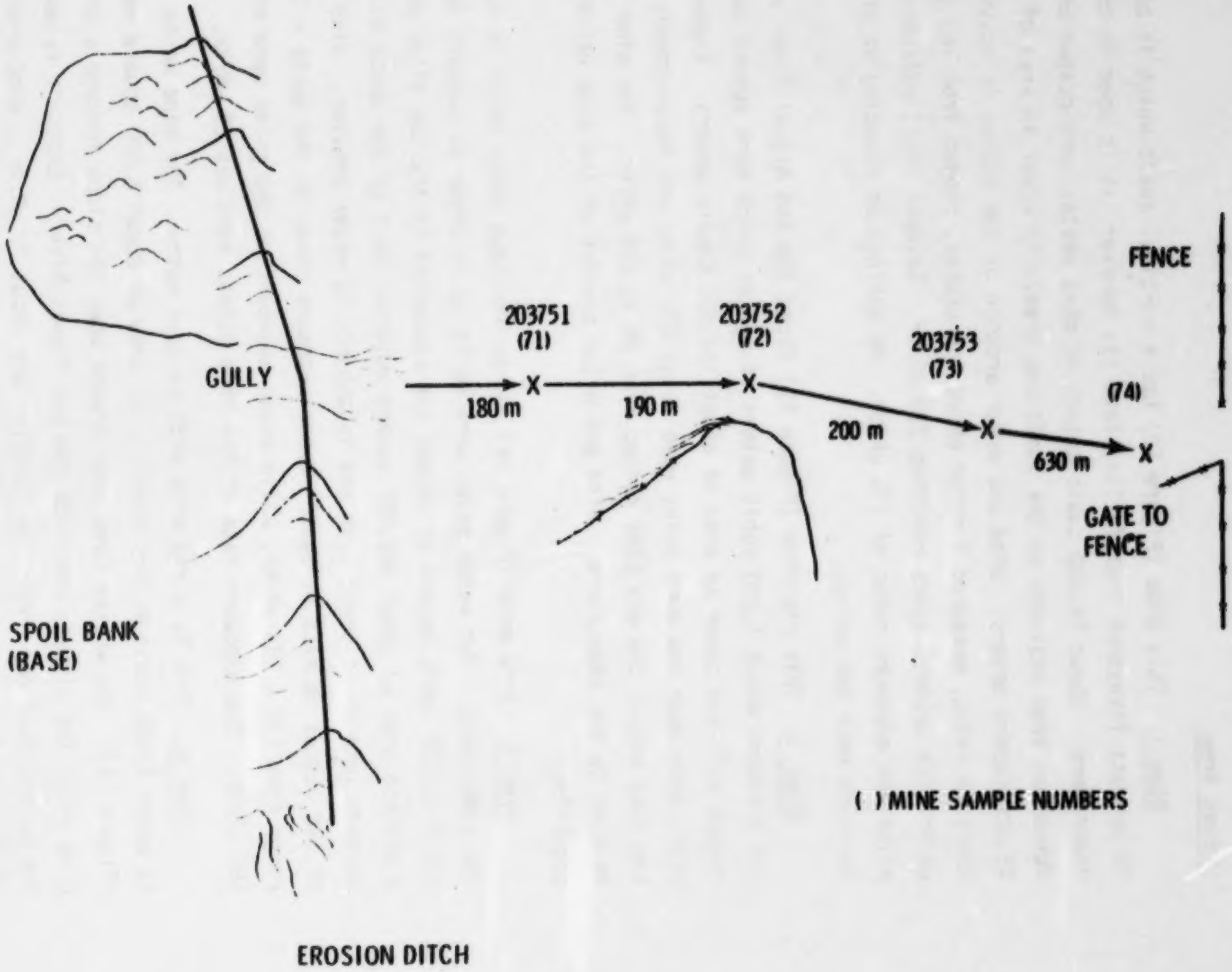

FENCE
203751
(71)
203752
(72)
203753
(73)
(74)
GULLY
180 m
190 m
200 m
630 m
GATE TO FENCE
SPOIL BANK (BASE)
( ) MINE SAMPLE NUMBERS
EROSION DITCH

Figure 11

Uravan Area

Mine 1. This mine (Figure 12) had a vertical shaft which is barricaded to prevent livestock from falling into it; however, it is open to the atmosphere. About 14,000 cubic meters of mine wastes were dumped on a downslope area adjacent to the shaft and presently cover an area of about 40,000 square meters. Wind and water erosion of the wastes is occurring. Exposure rates, measured 1 meter above the wastes, ranged from 140 to 170 µR/hr with several spots reaching 250 µR/hr. Several small adjacent waste piles had exposure rates of 110 µR/hr. No springs or standing water were observed near the wastes.

Mine 2. This rim mine (Figure 13) faces the San Miguel River valley and produced about 1,200 cubic meters of wastes which were dumped down the canyon wall and cover an area of about 160,000 square meters. Exposure rates made near the dump point were about 200 µR/hr and measurements on the road around the ore bins ranged from 50 to 150 µR/hr. The mine entry is open to the atmosphere. Wind and water erosion of the mine wastes is occurring.

Mine 3. This mine (Figure 14) has an inclined entry which is open to the atmosphere. Two waste piles were built up in order to support ore bins. About 40,000 cubic meters of wastes are contained in the two piles and have a surface area of about 640,000 square meters. Part of the waste piles extends into an adjacent wash and is subject to water erosion. Wind erosion of the wastes is also evident. Gamma exposure rates on the waste piles range from 120 - 150 µR/hr, while areas adjacent to the piles were about 160 µR/hr. The exposure rate on the mine access road was 80 µR/hr.

Mine 4. This is a rim mine with an open entry. The mine waste volume is about 6,000 cubic meters covering an area of about 4,000 square meters (Figure 15). The wastes have been eroded down the slope through a drain pipe under the highway and into the San Miguel River. Exposure rates on the access road and under the ore bins are about 70 µR/hr. Wind erosion of the wastes is evident.

Figure 12. Uravan Area - Mine 1

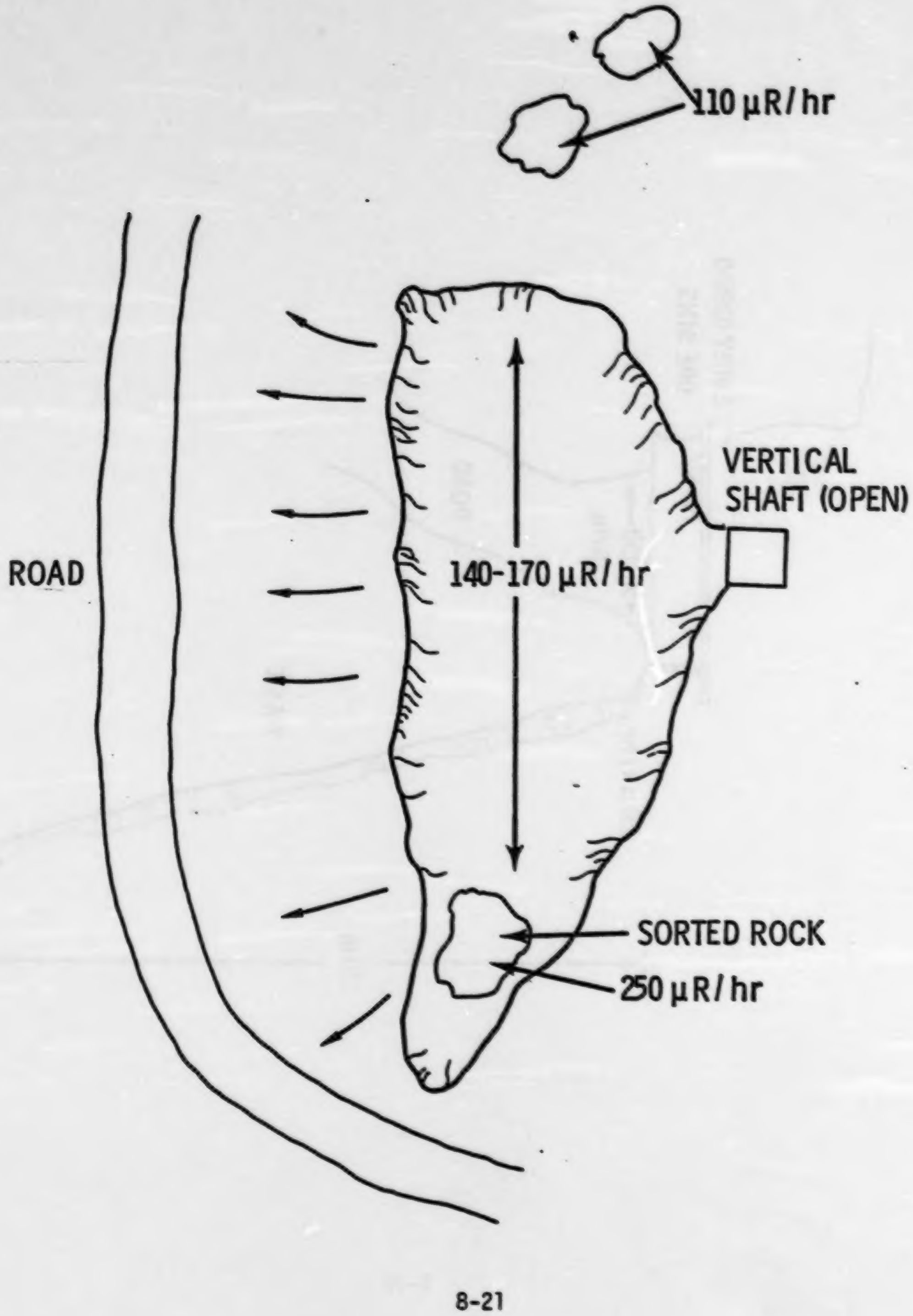

110 μR/hr
VERTICAL SHAFT (OPEN)
ROAD
140-170 μR/hr
SORTED ROCK
250 μR/hr

Figure 13. Uravan Area - Mine 2

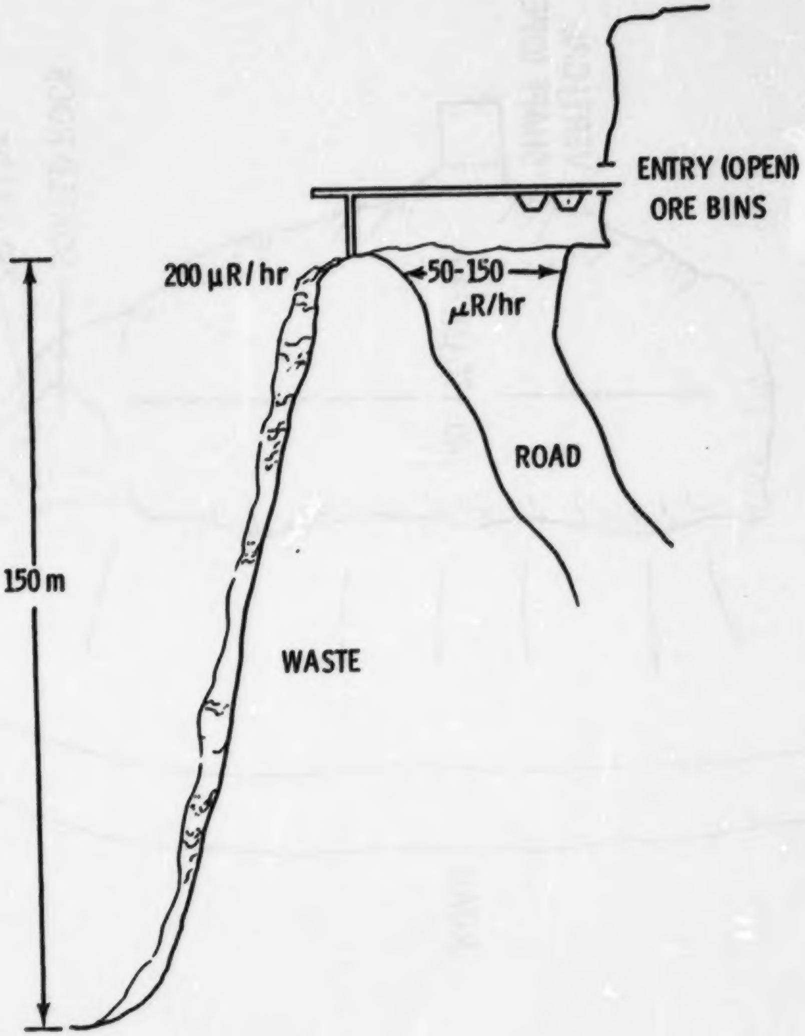

ENTRY (OPEN)
ORE BINS
200 μR/hr
50-150 μR/hr
ROAD
WASTE
150 m

Figure 14. Uravan Area - Mine 3

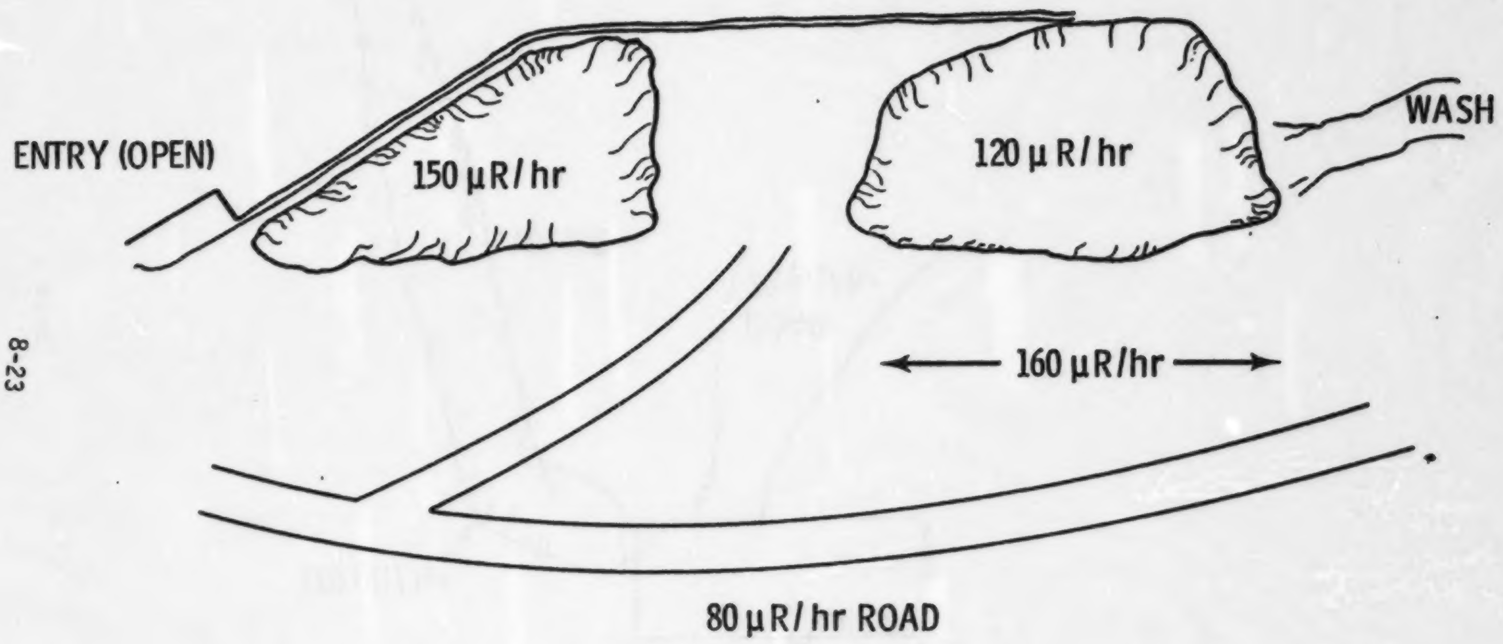
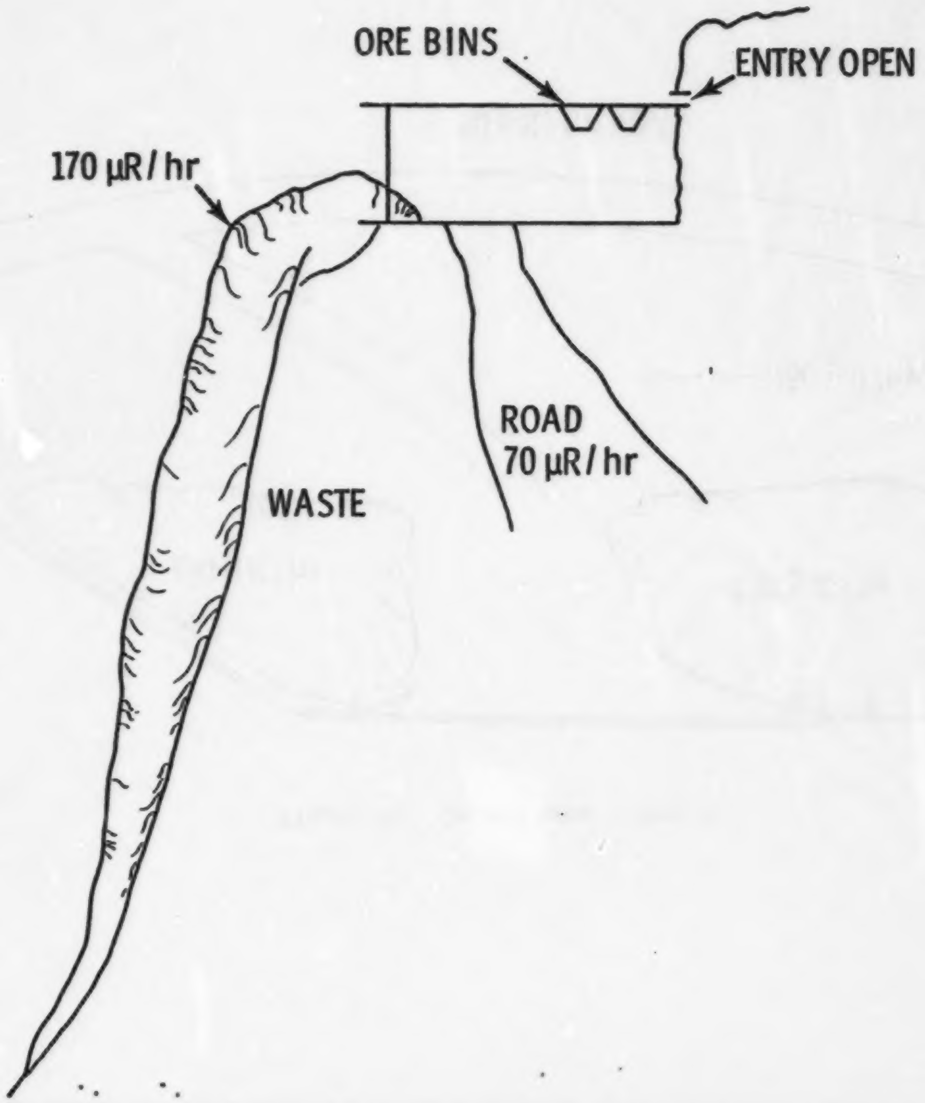

ENTRY (OPEN)
150 µR/hr
120 µR/hr
WASH
160 µR/hr
80 µR/hr ROAD

Figure 13. Uravan Area - Mine 4


ORE BINS
ENTRY OPEN
170 μR/hr
ROAD
70 μR/hr
WASTE

Mine 5. This mine contains a vertical shaft which is presently being used for forced ventilation of connecting mines (Figure 16). About 75,000 cubic meters of wastes were scattered over an area of about 50,000 square meters. Gamma exposure rates over the former waste area ranged from 50 - 150 μR/hr. Exposure rates over the consolidated piles range from 50 - 220 μR/hr. Wind and water erosion is evident at both the former and present waste storage areas.

Mine 6. This mine has a vertical shaft which is presently being used to force ventilate connecting active mines (Figure 17). About 45,000 cubic meters of wastes were dumped on a downslope adjacent to the mine shaft covering 4000 square meters of ground. Gamma exposure rates measured over the waste pile ranged from 180 - 220 μR/hr. Run-off and wind erosion of the wastes are evident. Some of the run-off appears to be entering a nearby stock pond.

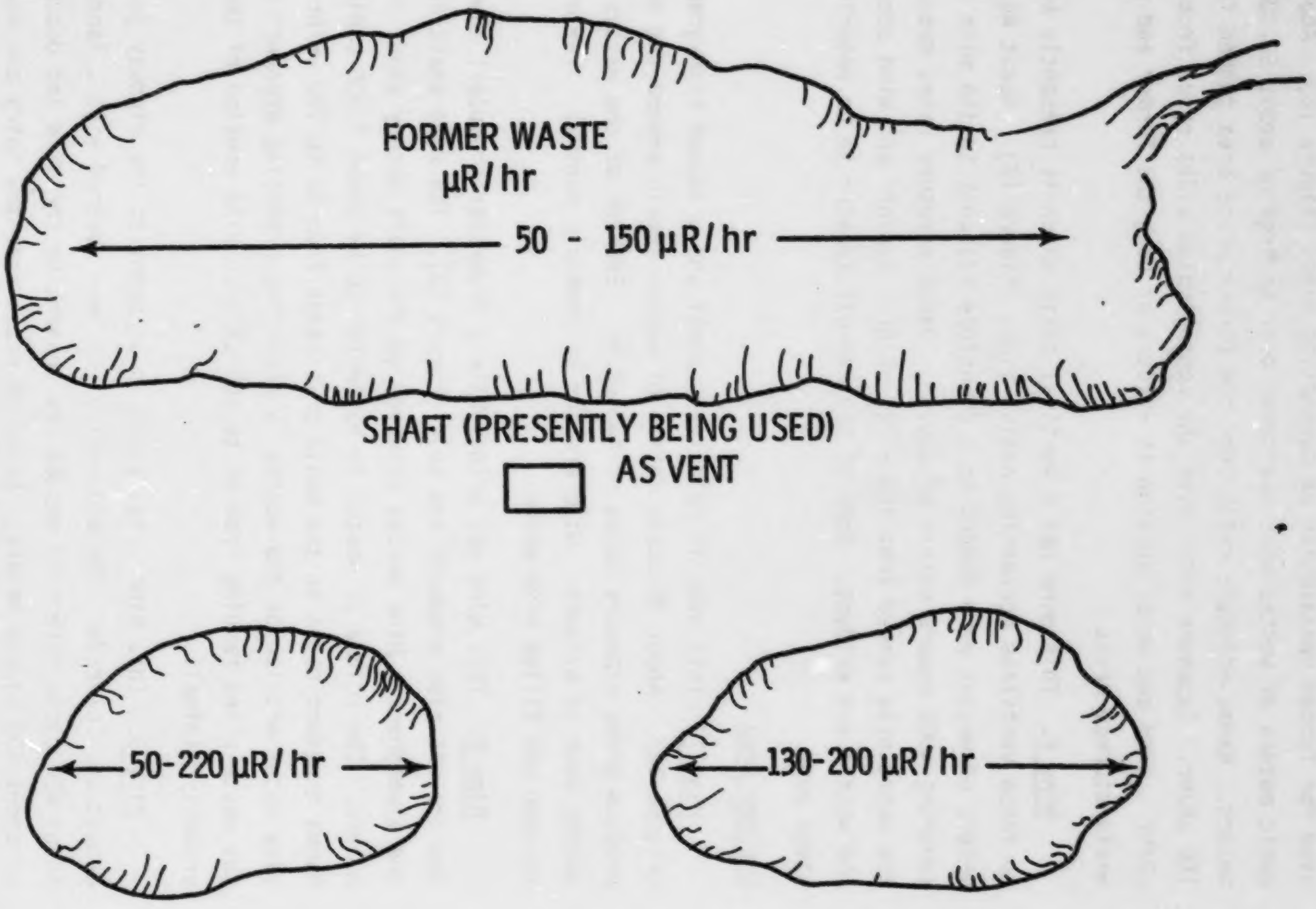
Boulder Area

Mine 7. This mine is relatively small and produced high-grade ore (Figure 18). About 35 cubic meters of wastes remain around the shaft and produce gamma exposure rates of 400 μR/hr. Erosion of the wastes into the nearby wash is evident. Wind erosion is probably minimal. The mine shaft is open and filled with water.

Mine 8. This mine was principally a fluorspar producer; however, uranium ore was also produced and sold (Figure 19). The mine shaft is open to the atmosphere. Mine wastes adjacent to the shaft occupy about 1000 square meters. The volume of wastes is estimated to be about 1,600 cubic meters. Gamma exposure rates on the waste pile range from 60 to 180 μR/hr. Extensive water erosion of the wastes is occurring producing exposure rates below the waste piles ranging from 40 to 100 μR/hr. Wind erosion of the wastes is probably minimal.

Mine 9. This mine (Figure 20) is adjacent to the highway just south of Jamestown, Colorado. The mine entry has been covered with a landslide. About 450 cubic meters of wastes are present on the site and occupy an area of about 400 square meters. Exposure rates near the entry are about 100 μR/hr and range from 40 to 60 μR/hr near the highway.

Figure 16. Uravan Area - Mine 5


FORMER WASTE
µR/hr
50 - 150 µR/hr
SHAFT (PRESENTLY BEING USED)
AS VENT
50-220 µR/hr
130-200 µR/hr

NOTE: WASTES FROM FORMER WASTE AREA
CONSOLIDATED INTO TWO PILES

Figure 17. Uravan Area - Mine 6

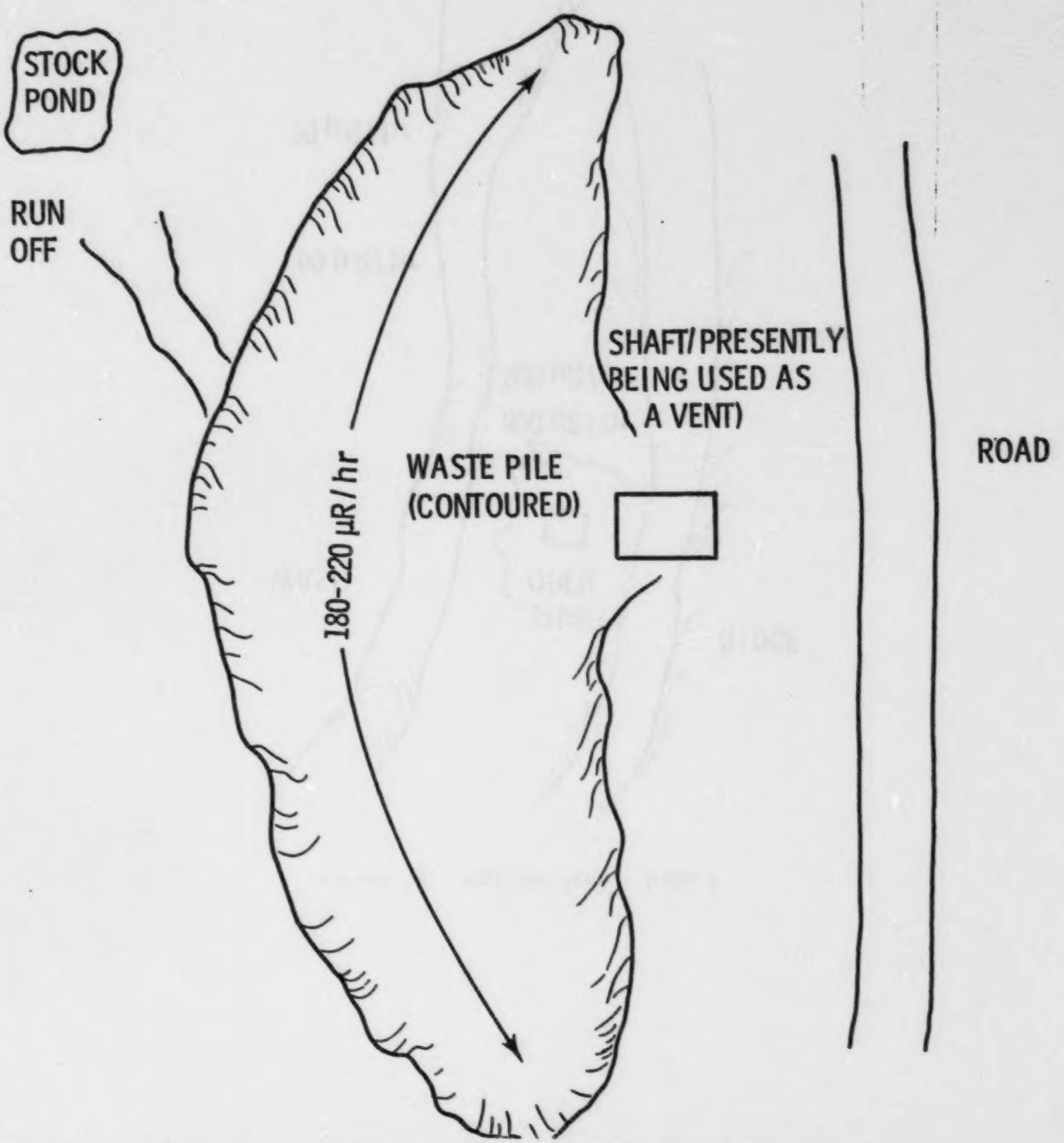

STOCK POND
RUN OFF
180-220 µR/hr
WASTE PILE (CONTOURED)
SHAFT/PRESENTLY BEING USED AS A VENT)
ROAD

Figure 18. Boulder Area - Mine 7

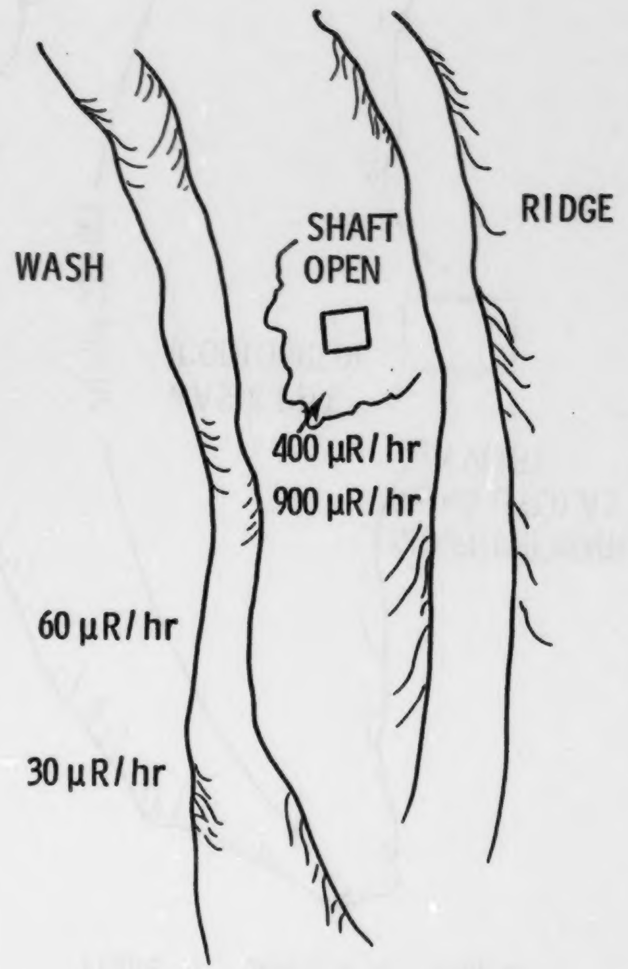

RIDGE
WASH
SHAFT
OPEN
400 µR/hr
900 µR/hr
60 µR/hr
30 µR/hr

Figure 19. Boulder Area - Mine 8

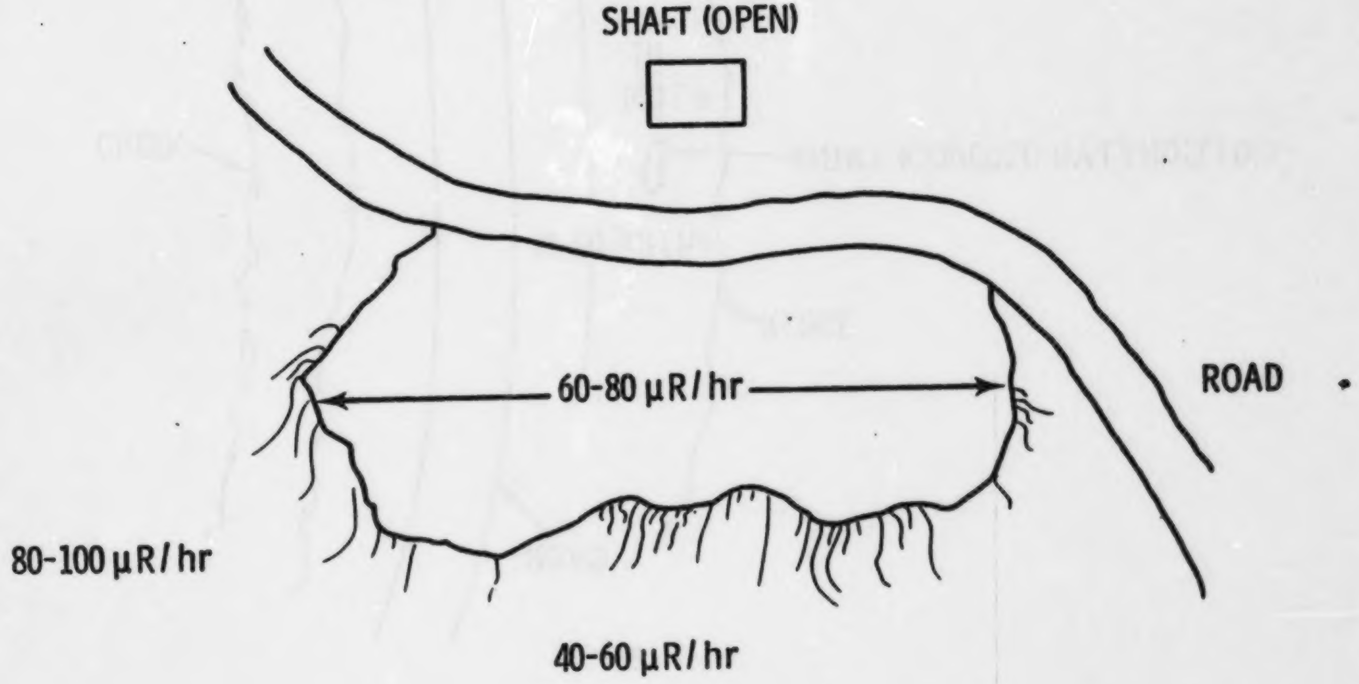
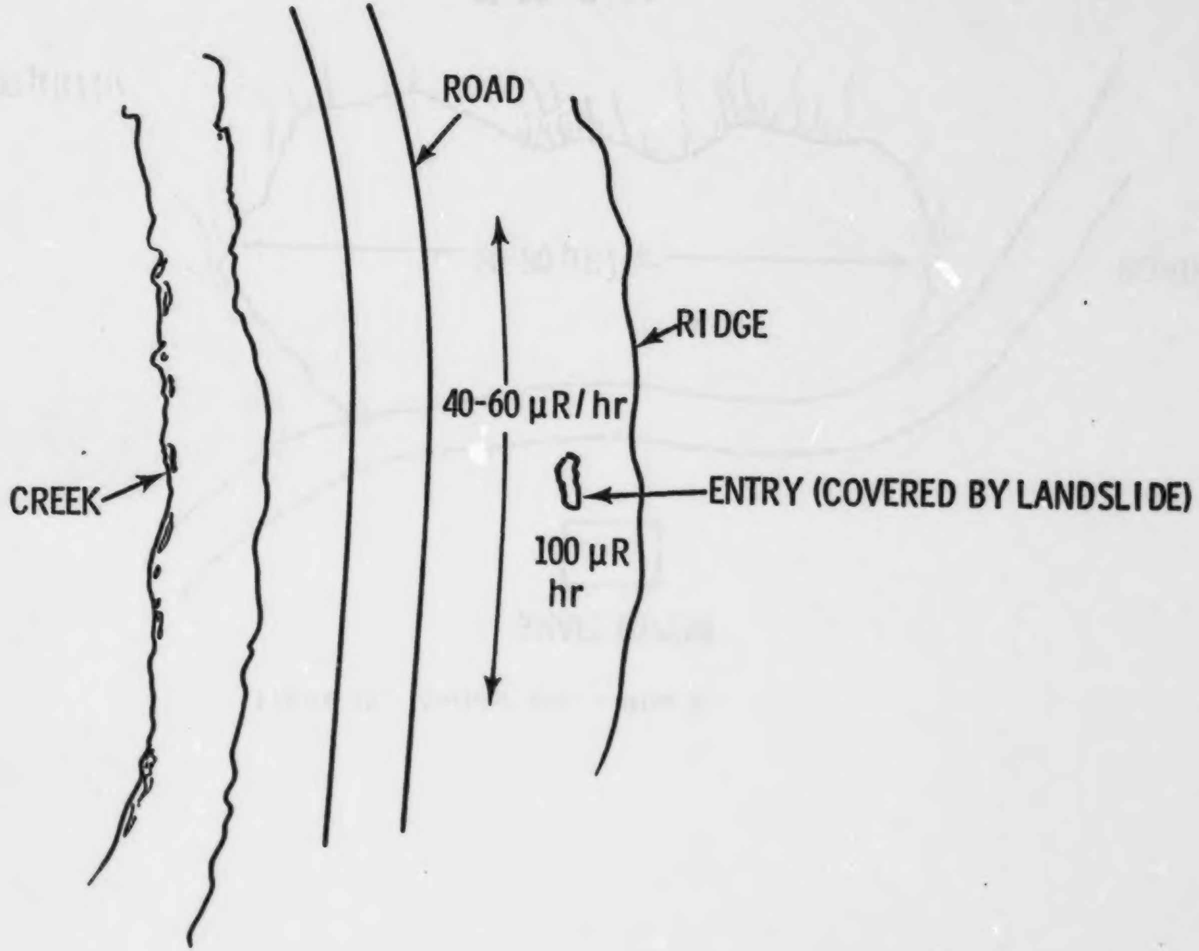

SHAFT (OPEN)
ROAD
60-80 μR/hr
80-100 μR/hr
40-60 μR/hr

Figure 20. Boulder Area - Mine 9


ROAD
RIDGE
40-60 μR/hr
CREEK
ENTRY (COVERED BY LANDSLIDE)
100 μR
hr

Mine 10. This mine is relatively small and has an open entry. Exposure rates near the entry range from 100 to 600 μR/hr. Exposure rates on the mine access road are about 70 μR/hr. Piles containing mine wastes occupy about 800 square meters with a volume of 150 cubic meters. Water and wind erosion of the wastes is evident (see Figure 21).

SUMMARY

Those mines surveyed in the Uravan area are probably typical of the many inactive uranium mines in that area. Most of the mines are relatively small and are underground. Wind and water erosion is occurring at all of the mines inspected, and all of the entries were open except where noted.

Ore haulage losses have occurred on the roads. In addition, mine wastes have been used for road ballast. The lands in the mining areas are used for grazing.

Exploratory drilling is abundant in the survey area and the resulting land damage is extensive. Little or no reclamation of drill sites was observed.

Mines 8 through 10 were surveyed near Jamestown, Colorado. These mines, although small, are typical of this area. Although uranium was not principally produced by many of these mines, the mine wastes are generally radioactive.

Mine wastes were used as fill for the Jamestown Park (210 acres) and are producing exposure rates of 40 to 100 μR/hr in that area. It appears that some dwellings may be built on or near the mine wastes. Surface and groundwater contamination from the old mining activities is likely.

RECOMMENDATIONS

Not appropriate.

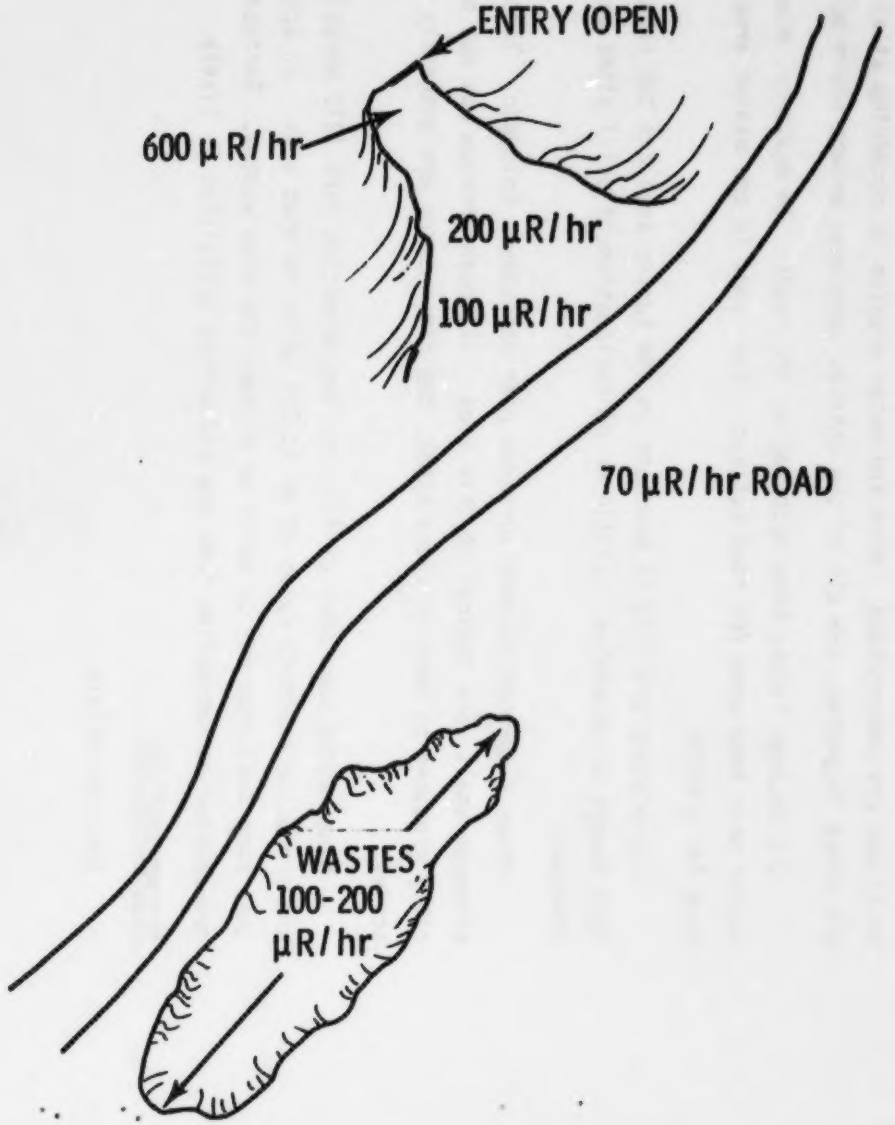

ENTRY (OPEN)
600 µ R/hr
200 µR/hr
100 µR/hr
70 µR/hr ROAD
WASTES
100-200
µR/hr

Figure 21. Boulder Area - Mine 10

TASK 9

GAMMA MAPPING

INTRODUCTION

A gamma survey of several inactive uranium mines was conducted using the NE 148 EPA scintillometer. Measurements taken with this instrument at a height of 1 meter and with the lead shield in place permitted direct measurements of the radiation exposures in µR/hr. Similar measurements with a pressurized ion chamber (PIC) also permitted measurements of the radiation exposure. Most of the measurements were made with the scintillometer, but the pressurized ion samples served as a primary reference standard for the measurements. Measurements were also made with the scintillometer right at the surface, both with and without the lead absorber in place. In this discussion, the gamma mapping of six uranium mine areas is described. These include Morton Ranch, San Mateo mine, Mesa Top mine, Poison Canyon Area #1, Poison Canyon Area #2, and Barbara J #3. Also included are measurements which were made by "walk through" at ten inactive mines in the Colorado area.

In addition to the scintillometer measurements mentioned above, measurements were taken with the lead shielding in place and the difference between these was recorded as delta values. These delta values may be useful in differentiating between natural radioactivity and radioactivity which has radionuclides in different ratios from those present in nature.

DISCUSSION

MORTON RANCH MINE

For the Morton Ranch open pit uranium mine environs, the gamma survey is shown in Figure 1. In most cases, radiation levels decrease as one moves outward from the uranium mine. On two of the sectors, the ones at 135° and at 180° from north, there is actually an increase with distance, followed by a decrease. These high points were found to be related to natural outcroppings of uranium ore rather than contamination from the mining operation. The principal winds in this area are from the southwest. It was observed, however, that on the 45° transect there was no significant increase in the gamma survey readings relative to other wind directions. One would there-

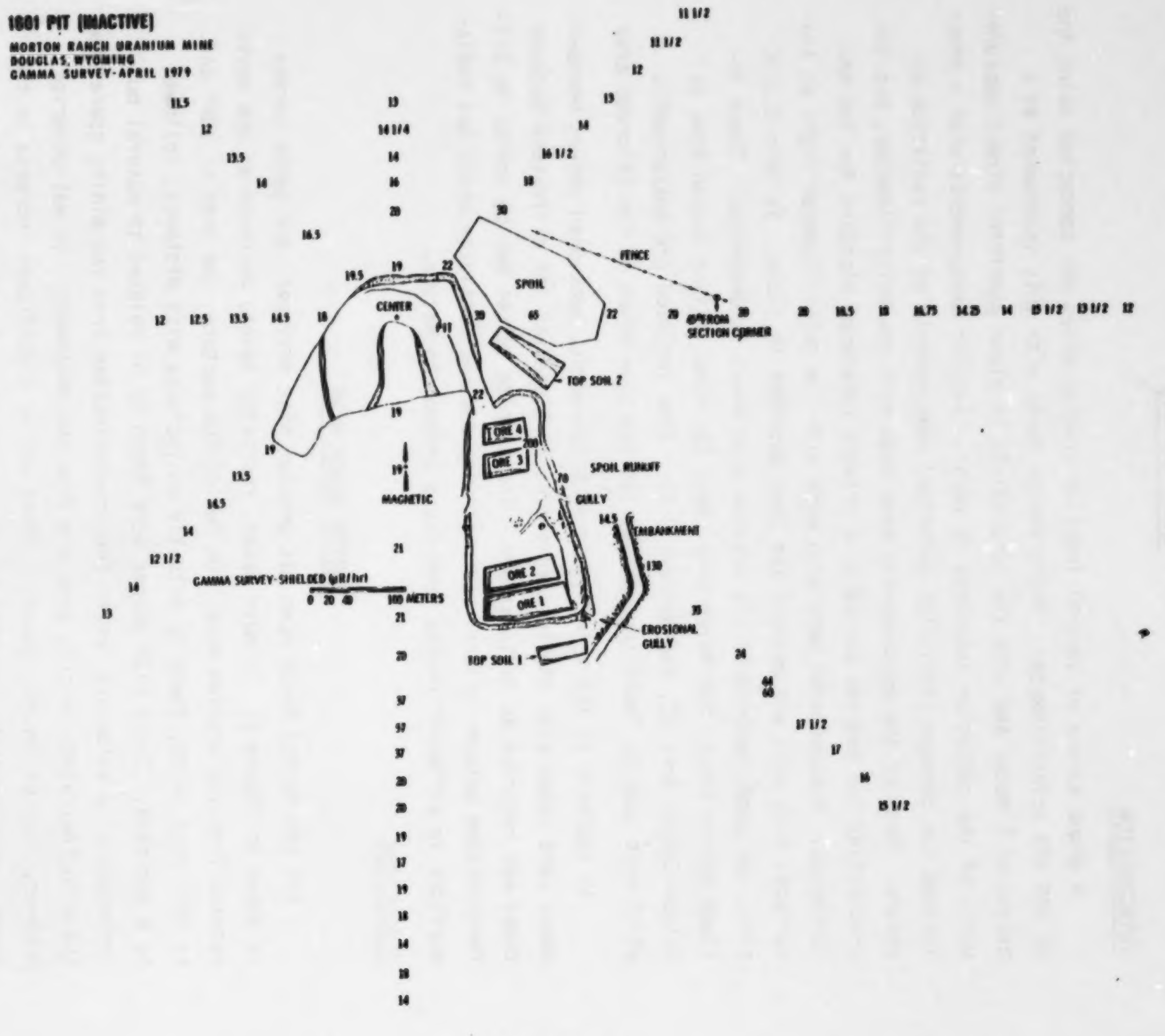

1601 PIT (INACTIVE)
MORTON RANCH URANIUM MINE
DOUGLAS, WYOMING
GAMMA SURVEY-APRIL 1979
GAMMA SURVEY-SHIELDED (μR/hr)
0 20 40 100 METERS
MAGNETIC
CENTER
PIT
SPOIL
FENCE
TOP SOIL 2
TOP SOIL 1
ORE 4
ORE 3
ORE 2
ORE 1
SPOIL RUNOFF
GULLY
EMBANKMENT
EROSIONAL GULLY
SECTION CORNER
11.5
12
13.5
14
16.5
19.5
19
13
14 1/4
14
16
20
11 1/2
11 1/2
12
13
14
16 1/2
18
30
22
12
12.5
13.5
14.5
18
20
65
22
20
20
20
16.5
18
16.75
14.25
14
15 1/2
13 1/2
12
22
19
19
19
13.5
14.5
14
12 1/2
14
13
200
70
14.5
130
35
21
21
20
24
44
60
17 1/2
17
16
15 1/2
37
37
37
20
20
19
17
19
18
14
18
14

FIGURE 1

fore conclude initially that wind transport of ore material from the mining operation was not significant.

Since uranium mines are located in areas which often have elevated surface radioactivity, considerable caution must be exercised in interpreting gamma radiation maps of inactive uranium mine areas. It would be expected that much of the radioactivity may be associated with natural outcroppings rather than contamination associated with the mining operation or with the wind erosion and subsequent transport of ore material.

In Figure 2 the delta readings, which are simply the difference between the scintillometer reading with and without the lead absorber in place, are plotted for the same locations as were presented in Figure 1. A review of these measurements simply indicates larger delta values are generally observed in areas of higher radioactivity. It does not appear, however, that the delta values will be useful in differentiating between natural radioactivity at the site and the radioactivity which has been transported as a result of the mining operation.

Figures 3 and 4 provide gamma surveys and delta values, respectively, for the open pit mine. The gamma survey, which includes readings in μR/hr (see Figure 3) shows values which are not substantially in excess of those observed in the immediate environs of the open pit. This, we believe, simply reflects the fact that the majority of the surface areas of the open pit are at any given time mainly composed of waste material. As indicated in Figure 4, the delta values do not appear to provide any unique information that is not already indicated by the gamma survey.

To get a better indication of the value of the scintillometer readings, measurements were made at several locations by the scintillometer with the lead shield in place and with the pressurized ion chamber. These readings are plotted in Figure 5. It is apparent that a linear relationship between these observations exists and therefore it is reasonable to use the scintillometer measurements for estimating the radiation exposure. A regression analysis of the relationship is shown in the following equation:

$$\text{Shielded NE 148A } (\mu\text{R/hr}) = \sim 1.06 + 0.971 \, [\text{PIC reading } (\mu\text{R/hr})].$$

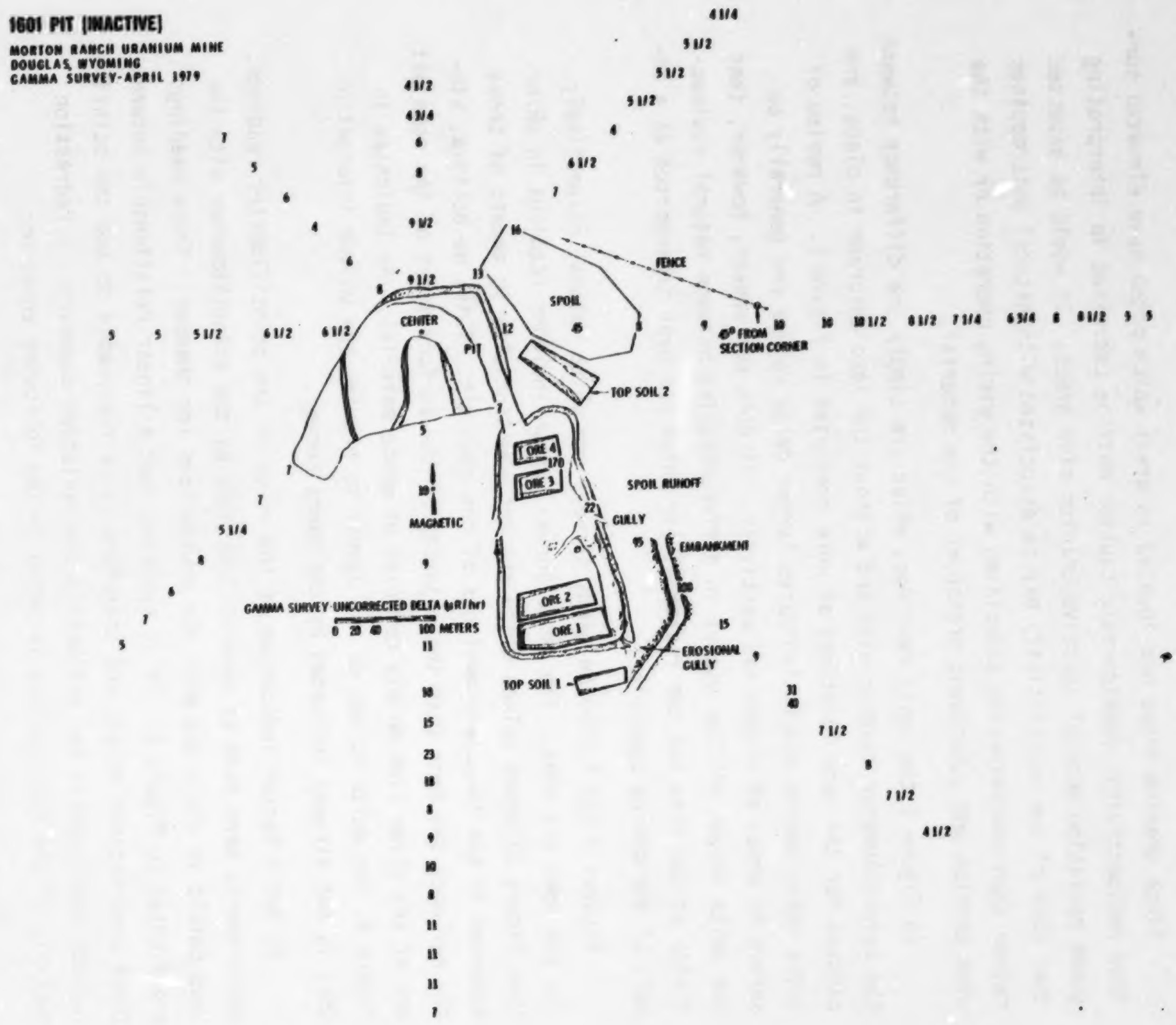
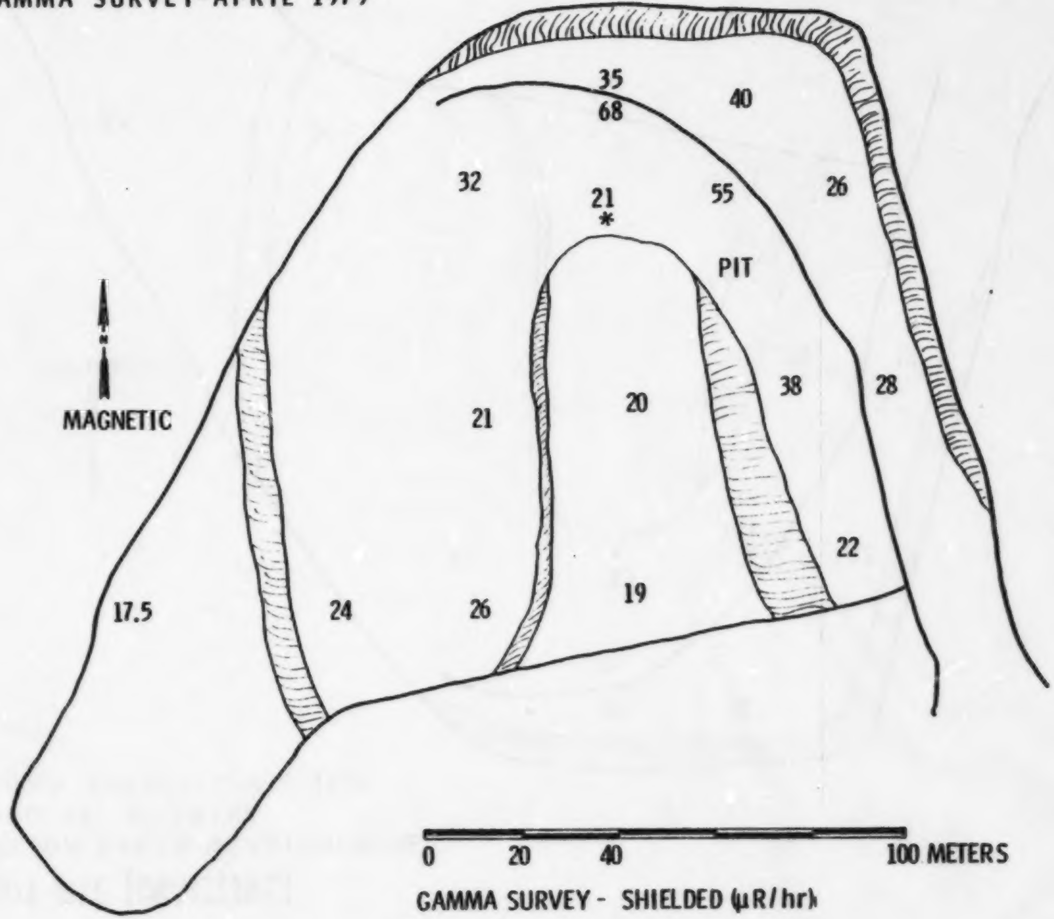

1601 PIT (INACTIVE)
MORTON RANCH URANIUM MINE
DOUGLAS, WYOMING
GAMMA SURVEY-APRIL 1979
GAMMA SURVEY-UNCORRECTED DELTA (μR/hr)
0 20 40 100 METERS
MAGNETIC
CENTER
PIT
SPOIL
FENCE
45° FROM SECTION CORNER
TOP SOIL 2
ORE 4
ORE 3
ORE 2
ORE 1
SPOIL RUNOFF
GULLY
EMBANKMENT
EROSIONAL GULLY
TOP SOIL 1
4 1/4
5 1/2
5 1/2
5 1/2
4
6 1/2
7
16
13
4 1/2
4 3/4
6
8
9 1/2
9 1/2
7
5
6
4
6
8
5
5
5 1/2
6 1/2
6 1/2
12
45
8
9
10
10
10 1/2
8 1/2
7 1/4
6 3/4
8
8 1/2
9
9
7
5
170
22
95
100
10
7
7
5 1/4
8
6
7
5
9
11
10
15
23
18
8
9
10
8
11
11
11
7
15
9
31
40
7 1/2
8
7 1/2
4 1/2

FIGURE 2

1601 PIT (INACTIVE)

MORTON RANCH URANIUM MINE
DOUGLAS, WYOMING
GAMMA SURVEY-APRIL 1979

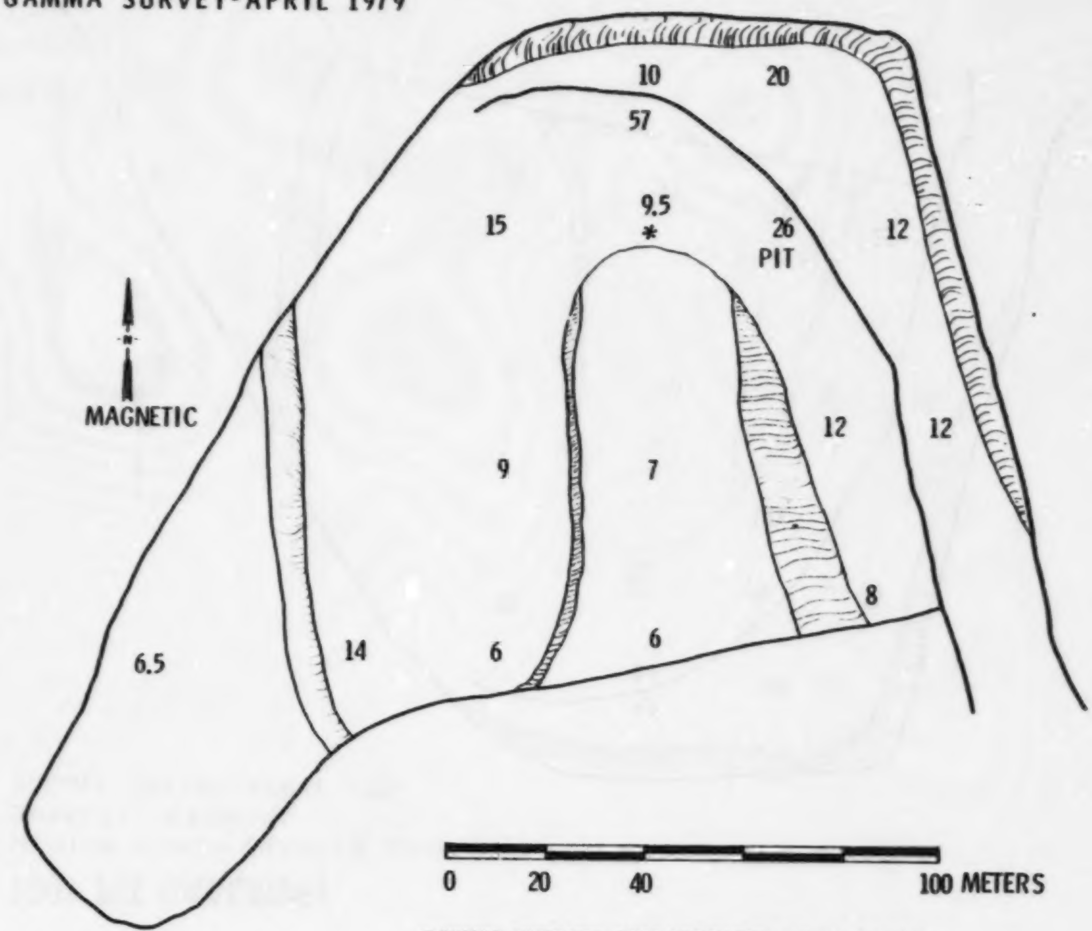

35
68
40
32
21
*
55
26
PIT
MAGNETIC
21
20
38
28
22
17.5
24
26
19
0
20
40
100 METERS

GAMMA SURVEY - SHIELDED (μR/hr)

FIGURE 3

1601 PIT (INACTIVE)

MORTON RANCH URANIUM MINE
DOUGLAS, WYOMING
GAMMA SURVEY-APRIL 1979


10
20
57
9.5
*
15
26
PIT
12
MAGNETIC
12
12
9
7
8
6.5
14
6
6
0
20
40
100 METERS

GAMMA SURVEY - UNCORRECTED DELTA (µR/hr)

FIGURE 4

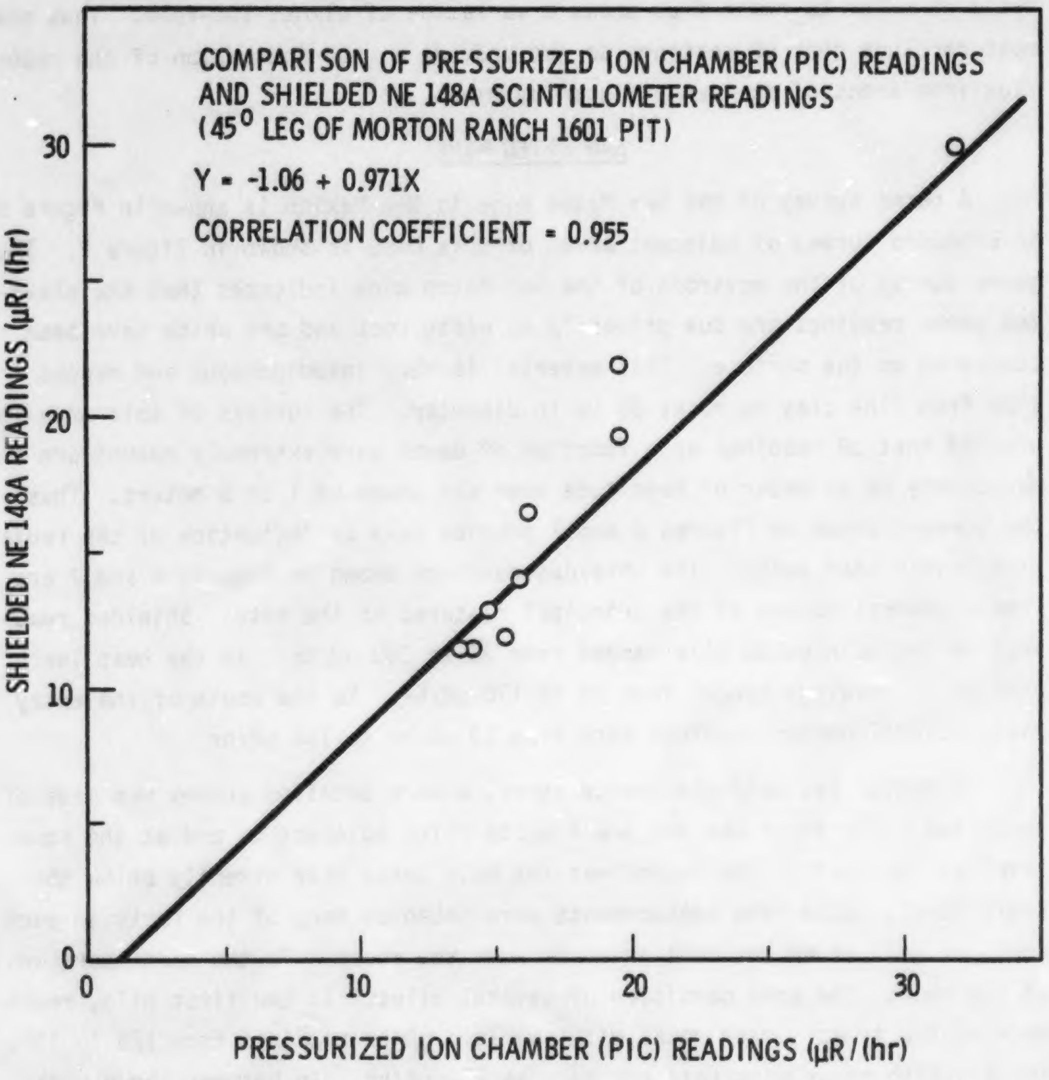

COMPARISON OF PRESSURIZED ION CHAMBER (PIC) READINGS
AND SHIELDED NE 148A SCINTILLOMETER READINGS
(45° LEG OF MORTON RANCH 1601 PIT)
Y = -1.06 + 0.971X
CORRELATION COEFFICIENT = 0.955
SHIELDED NE 148A READINGS (μR/(hr)
30
20
10
0
0
10
20
30
PRESSURIZED ION CHAMBER (PIC) READINGS (μR/(hr)

FIGURE 5

The correlation coefficient for these data is 0.955. Thus there is an excellent agreement between the readings obtained on the two instruments.

It was also of interest to show the relationship between the gamma survey readings and the radon flux. This relationship is shown in Table 1 for 17 locations at the Morton Ranch site. It seems rather surprising that the ratio of μR/hr to radon flux shows a variation of almost 100-fold. Thus one must conclude that μR readings do not provide a good indication of the radon flux from areas of an open pit uranium mine.

SAN MATEO MINE

A gamma survey of the San Mateo mine in New Mexico is shown in Figure 6. An expanded survey of adjacent areas of this mine is shown in Figure 7. The gamma survey of the environs of the San Mateo mine indicates that the elevated gamma readings are due primarily to waste rock and ore which have been scattered on the surface. This material is very inhomogeneous and ranges in size from fine clay to rocks 30 cm in diameter. The surveys of this area indicated that μR readings as a function of depth were extremely nonuniform and would vary by an order of magnitude over distances of 1 or 2 meters. Thus the surveys shown in Figures 6 and 7 provide only an indication of the radiation levels that exist. The shielded readings shown in Figures 6 and 7 are from a general survey of the principal features of the site. Shielded readings on the main waste pile ranged from 35 to 300 μR/hr. In the heap leach pond these readings ranged from 95 to 170 μR/hr. To the south of the entry road, scintillometer readings were from 13 μR/hr to 118 μR/hr.

To better evaluate the source terms, a more detailed survey was made of two areas. The first was the small waste piles adjacent to and at the same level as the shaft. The second was the main waste pile directly below the shaft level. Base rate measurements were taken on many of the rocks in each area, as well as on the soil areas between the rocks. To the north-northwest of the shaft, the area consisted of several piles. In the first pile, rocks were of two types: grey rocks with shielded μR/hr readings from 125 to 135, and blackish rocks with readings such as 250 μR/hr. In between these rocks was soil which ranged from 100 to 125 μR/hr. The light rocks made up about 5% of the surface, whereas dark rocks accounted for less than 1%. Small piles

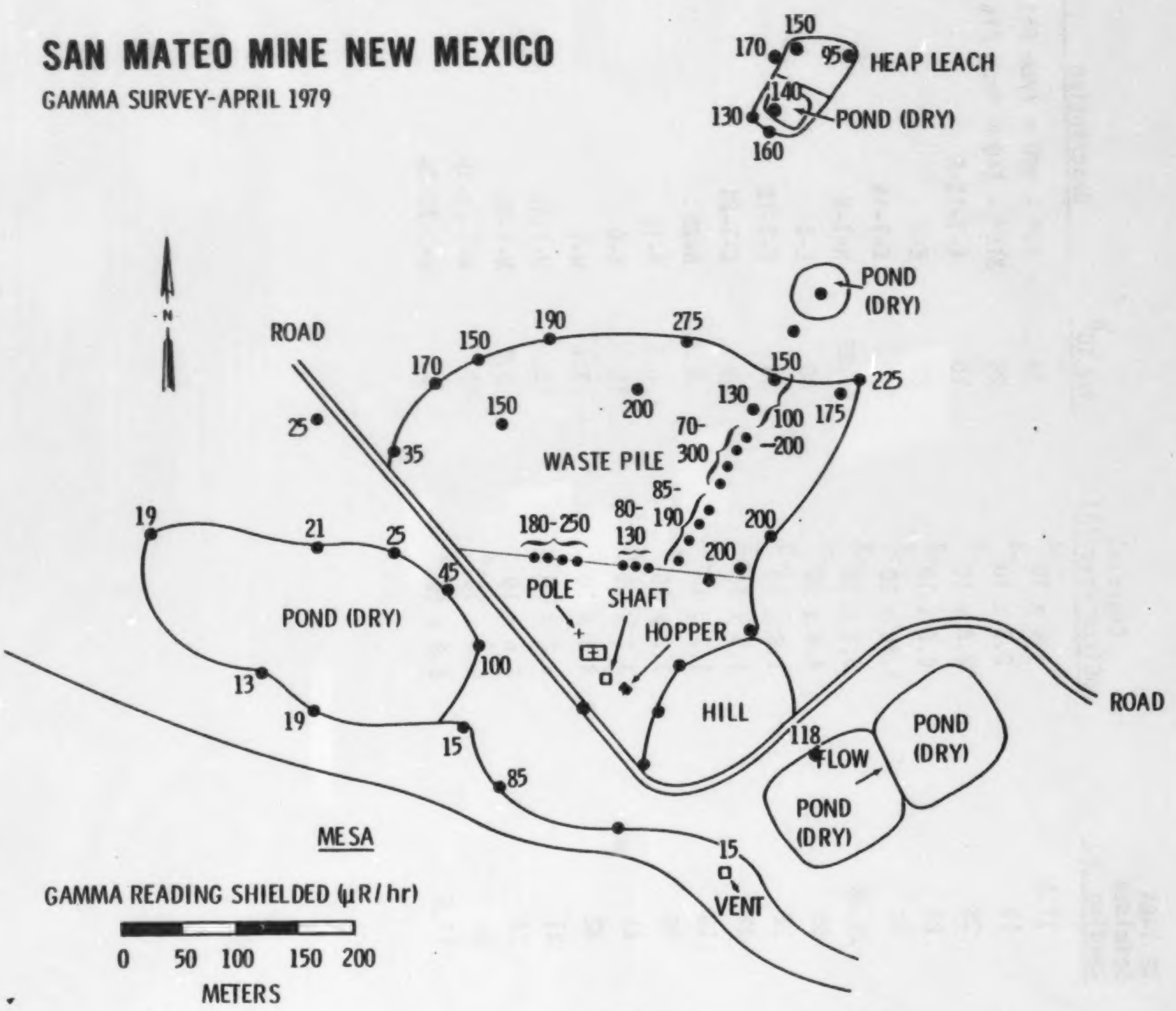
TABLE 1

A Comparison of Radon Flux to Dose Readings as Measured by the E.P.A. NE 148A Scintillometer

NE 148A Shielded Reading (A)	Charcoal pCi/cm^2-sec (R)	R/A 10^6	Description
11.5	1.6×10^{-4}	14	45° - 490 m from Pit
12	2.9×10^{-4}	24	315° - 240 m from Pit
28	2.8×10^{-4}	10	E-1-1S-E
26	6.6×10^{-4}	25	E-2
40	1.36×10^{-2}	340	E-1-1N
35,68	5.8×10^{-3}	166,85	N-1-N
55	4.4×10^{-3}	80	E-1
38	1.0×10^{-3}	26	E-1-1S
22	1.3×10^{-3}	59	E-1-2S
19	1.7×10^{-4}	9	N-2S
20	1.3×10^{-4}	6.5	N-1S
21	3.1×10^{-4}	15	N-0
32	8.3×10^{-5}	2.6	W-1
21	3.2×10^{-4}	15	W-1-1S
26	9.6×10^{-5}	3.7	N-1-2S
24	9.6×10^{-4}	40	W-1-2S-1W
17.5	8.8×10^{-5}	5	W-1-2S-2W

SAN MATEO MINE NEW MEXICO

GAMMA SURVEY-APRIL 1979



150
170
95
HEAP LEACH
140
POND (DRY)
130
160
POND
(DRY)
N
ROAD
190
275
150
170
225
150
130
175
200
100
-200
25
70-
300
35
WASTE PILE
85-
190
19
21
25
180-250
80-
130
200
200
45
POLE
SHAFT
POND (DRY)
HOPPER
100
13
HILL
ROAD
19
15
118
FLOW
POND
(DRY)
85
POND
(DRY)
MESA
15
VENT
GAMMA READING SHIELDED (μR/hr)
0
50
100
150
200
METERS

FIGURE 6

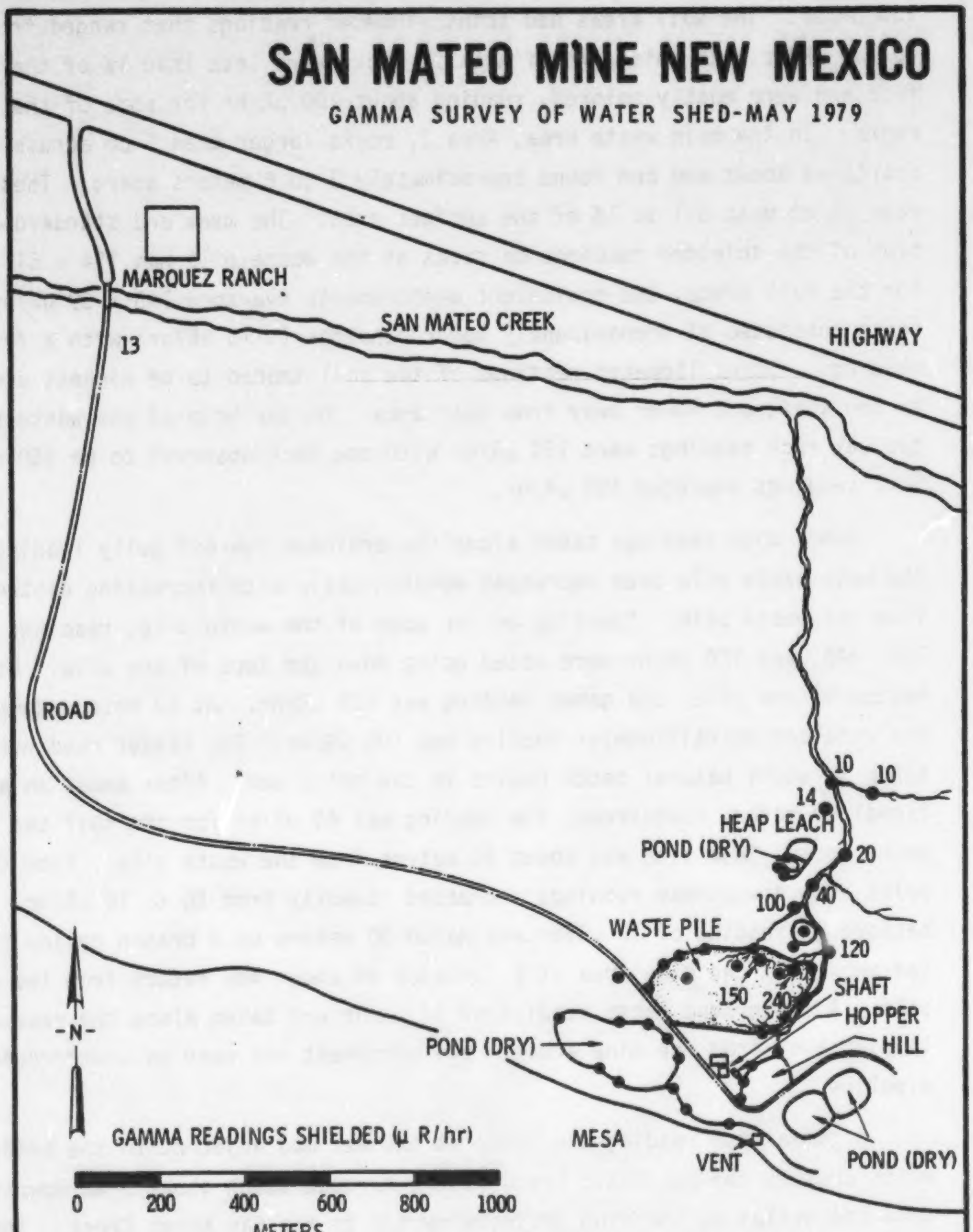

SAN MATEO MINE NEW MEXICO
GAMMA SURVEY OF WATER SHED-MAY 1979
MARQUEZ RANCH
SAN MATEO CREEK
HIGHWAY
13
ROAD
10
10
14
HEAP LEACH
POND (DRY)
20
40
100
WASTE PILE
120
150
240
SHAFT
HOPPER
HILL
POND (DRY)
MESA
VENT
POND (DRY)
N
GAMMA READINGS SHIELDED (μ R/hr)
0
200
400
600
800
1000
METERS

FIGURE 7

of waste due north of the shaft consisted of coarse gravel aggregate with dark grey soil interspersed in the pile. The aggregate areas ranged from 100 to 130 μR/hr. The soil areas had scintillometer readings that ranged from 80 to 130 μR/hr. In this part of Area 1, rocks were less than 1% of the surface and were mostly colored, reading about 100 μR/hr for some of the dark rocks. In the main waste area, Area 2, rocks larger than 5 cm across are scattered about and are found approximately 3 to 6 meters apart. These rocks make up at most 0.1 to 1% of the surface area. The mean and standard deviation of the shielded readings on rocks at the waste pile was 134 ± 61 μR/hr. For the soil areas, the equivalent measurements averaged 145 ± 39 μR/hr. The rocks consisted of predominantly lower readings (∿110 μR/hr) with a few higher readings. Scintillometer readings of the soil tended to be highest closest to the shaft and lower away from that area. On the brim of the waste pile, typical rock readings were 150 μR/hr with one rock observed to be 350 μR/hr. Soil readings averaged 185 μR/hr.

Gamma dose readings taken along the drainage run-off gully leading from the main waste pile area decreased monotonically with increasing distance from the waste pile. Starting on the edge of the waste pile, readings of 100, 240, and 120 μR/hr were noted going down the face of the pile. At the bottom of the pile, the gamma reading was 120 μR/hr. At 60 meters downstream, the shielded scintillometer reading was 100 μR/hr. The latter readings were taken in small natural catch basins in the gully bed. After about an additional 60 meters downstream, the reading was 40 μR/hr for the soil and an exposed rock. This site was about 90 meters from the waste pile. From this point, the downstream readings decreased steadily from 20 to 10 μR/hr. A background reading of 10 μR/hr was noted 30 meters up a branch gulley that led away from the mine area at a distance of about 460 meters from the waste pile. A background gamma reading of 10 μR/hr was taken along the roadway leading away from the mine area to the northwest and near an underground gas pipeline.

A gamma dose reading was taken on the wet mud adjacent to the bridge which crosses the San Mateo Creek at the Marquez ranch about 3 km downstream from the outlet of the mine drainage system to the San Mateo Creek. This reading was 13 μR/hr. The source of this increased reading is not known.

It may not originate with the mine drainage effluent since lower shielded scintillometer readings were noted far upstream in the drainage gully. It is possible that mine waste has been used as fill and roadbed material along the creek, and that this locally deposited rock is the source of the elevated reading.

In summary, the gamma field readings diminished steadily with distance from the waste pile area of the San Mateo mine. Background readings were obtained about 460 meters from the pile. On the waste pile and heap leach pile, gamma readings were quite variable and depended on the grade of locally deposited material adjacent to the scintillometer. Most of the source materials consisted of fine grey sand or clay interspersed with rocks. These rocks were mostly light colored and of low grade. A small percentage of high grade rocks was observed to be present at the surface.

MESA TOP MINE

Gamma readings at the Mesa Top mine in New Mexico (Figure 8) were taken only on and around the waste pile. Since this mine is located adjacent to numberous other abandoned mines, defining the boundary between each mine was not possible. In this field survey there was an insufficient amount of time to measure the dose from the entire complex of mine sites. In this limited survey, the gamma readings ranged from a low of 25 μR/hr on the periphery of the waste to a high of 290 at one location on a subore pile. The high readings were accompanied by elevated unshielded readings as well, indicating the source was adjacent to the scintillometer.

POISON CANYON #1 MINE

The Poison Canyon Area No. 1 consisted of three small pits with waste piles on the north side and a terraced area to the south. The highest readings in this site were in pit No. 1. Shielded readings of 50 to 165 μR/hr were observed there. The background in this area was 25 μR/hr. Gamma readings on the terraced area were slightly higher than the background values. The highest shielded scintillometer readings on the waste piles were 75 and 110 μR/hr (see Figure 9).

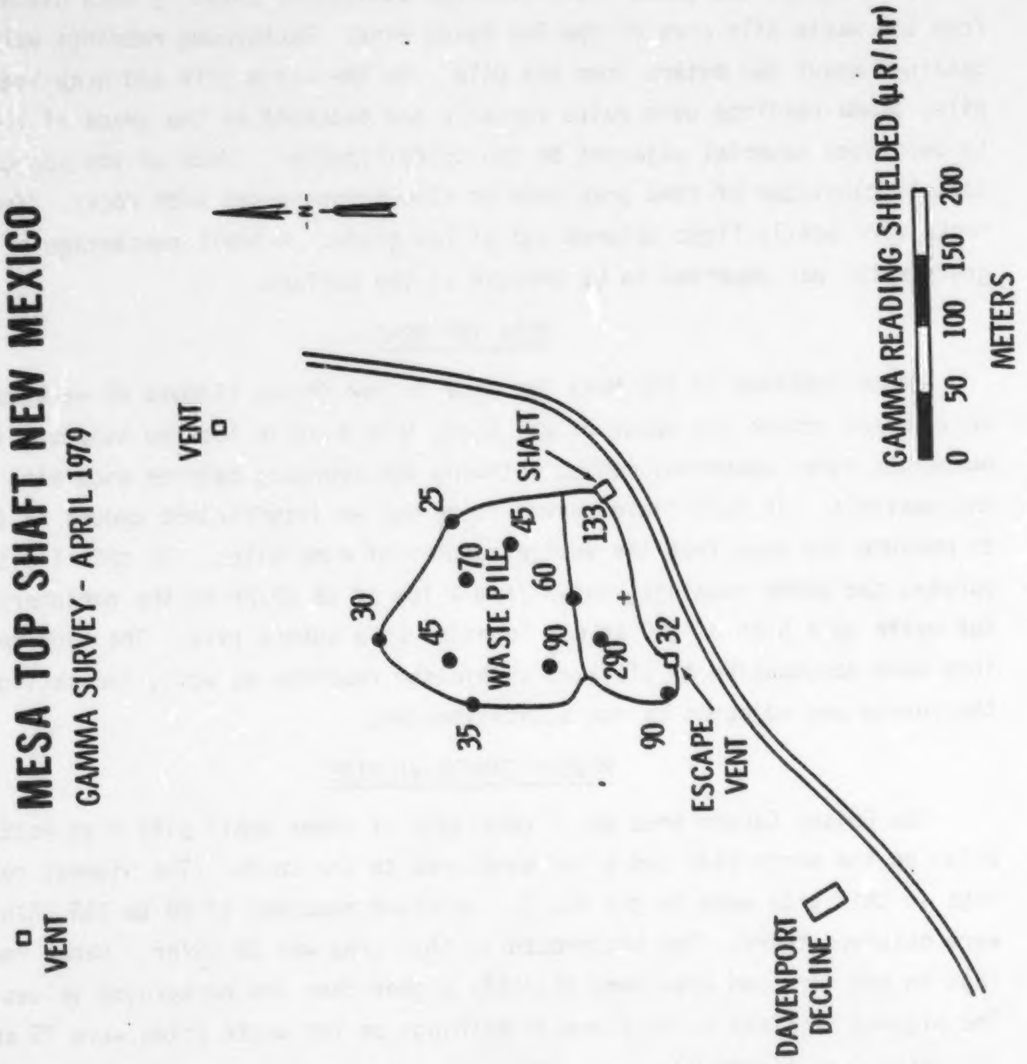

MESA TOP SHAFT NEW MEXICO
GAMMA SURVEY - APRIL 1979
VENT
VENT
N
SHAFT
WASTE PILE
ESCAPE VENT
DAVENPORT DECLINE
30
25
45
70
45
35
90
60
133
290
32
90
+
GAMMA READING SHIELDED (µR/hr)
0
50
100
150
200
METERS

FIGURE 8

POISON CANYON AREA #1 NEW MEXICO

GAMMA SURVEY-APRIL 1979

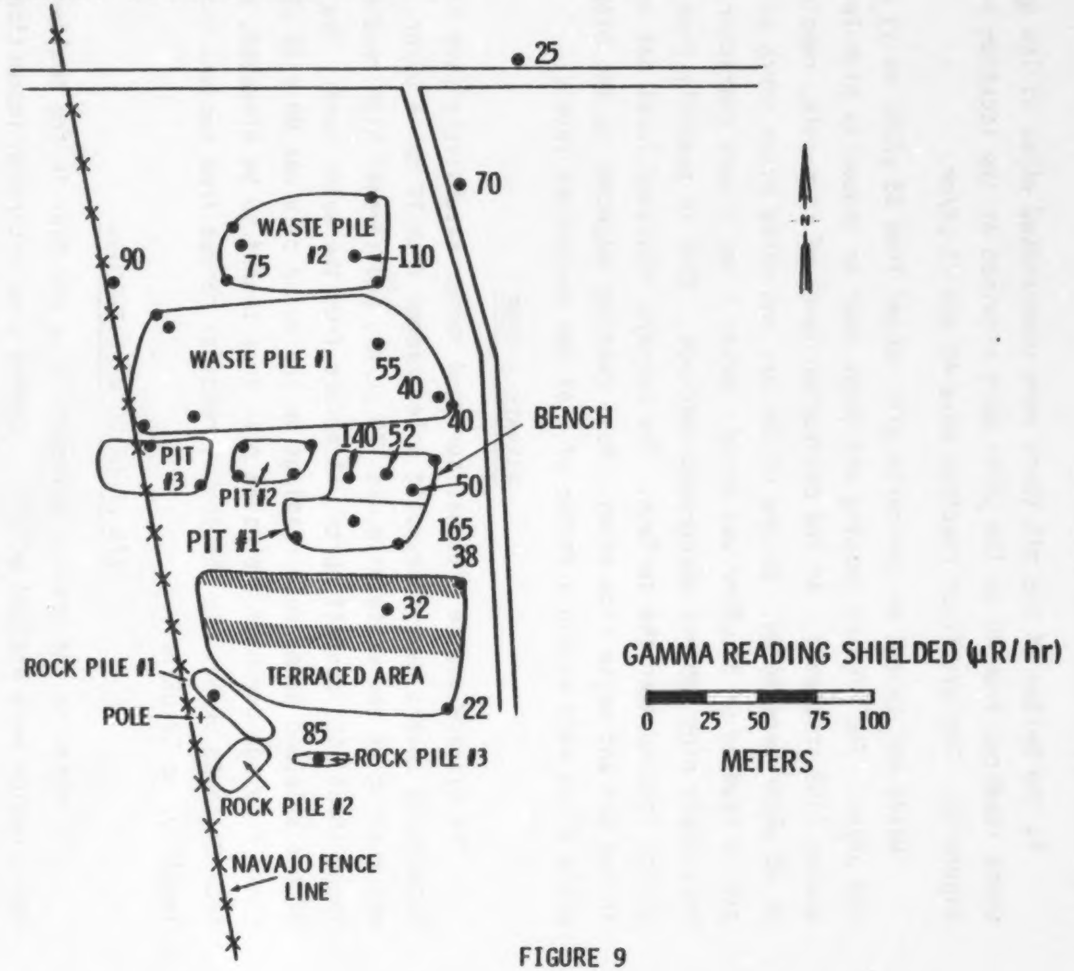

25
70
N
WASTE PILE #2
75
110
90
WASTE PILE #1
55
40
40
BENCH
PIT #3
PIT #2
140
52
50
PIT #1
165
38
32
TERRACED AREA
22
ROCK PILE #1
POLE
85
ROCK PILE #3
ROCK PILE #2
NAVAJO FENCE LINE
GAMMA READING SHIELDED (μR/hr)
0
25
50
75
100
METERS

FIGURE 9

POISON CANYON #2 MINE

At Poison Canyon Area No. 2 a single pit was sited between two overburden piles. Gamma readings were taken on the pit rim at regular intervals. Most of these gamma readings were approximately 30 ± 5 μR/hr. A single reading of 75 μR/hr was also observed.

At the bottom of the pit there were unexcavated piles of low grade ore. Gamma readings from 40 to 190 μR/hr were obtained at the location shown in Figure 10. The pit floor readings were 40 and 65 μR/hr.

Waste and subore on the north pile ranged from 65 μR/hr up to a high of 250 μR/hr. The highest reading was taken near an unusually high-level local source (250 shielded). At the overburden level of this pile, readings of 25 to 65 μR/hr were noted. On one of the ore and waste piles south of the open pit, a reading of 55 μR/hr was noted. Areas 1 and 2 were characterized by relatively high ambient background readings. This is possibly from ore deposits located near the surface. The surveys indicated local hot spots within the pit and waste site areas. Most readings adjacent to the pits and waste piles were within a factor of 2 of the background levels.

BARBARA J MINE

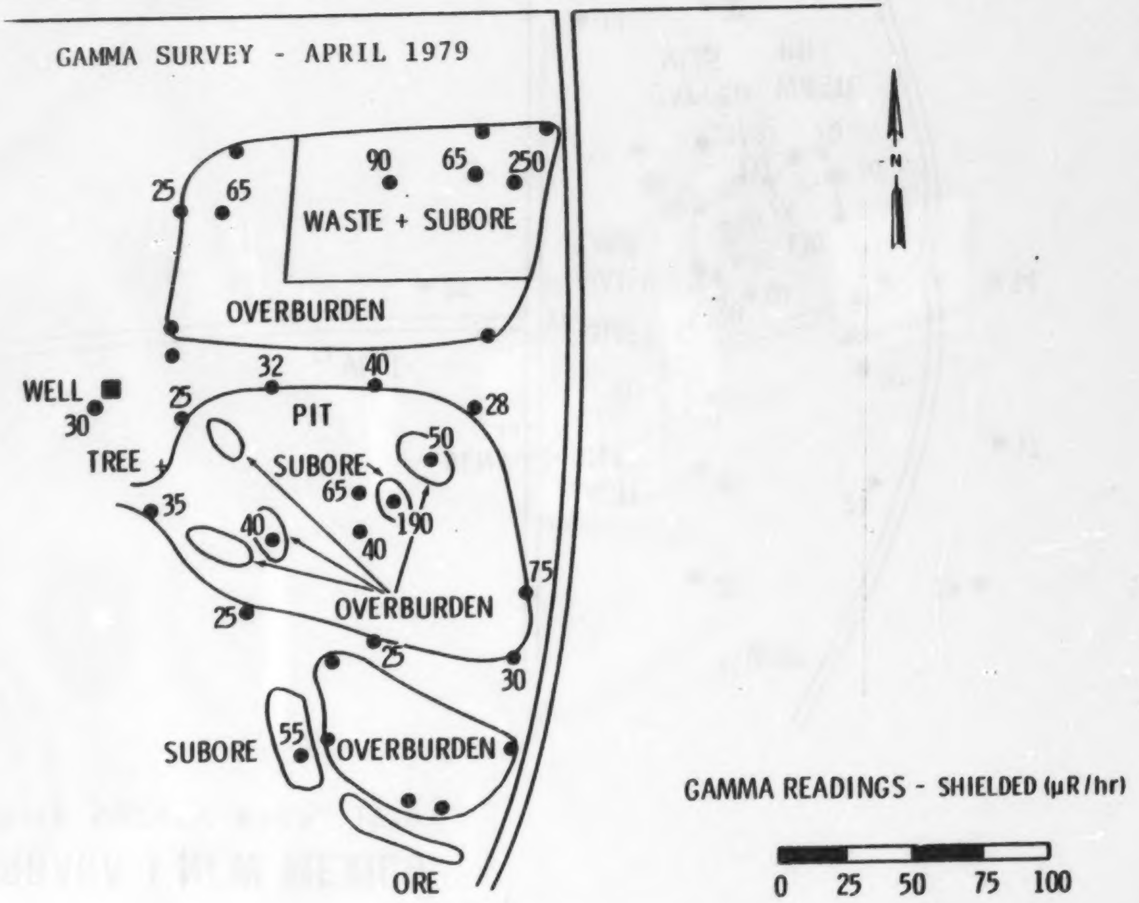
The Barbara J mine site was surveyed rather extensively (see Figure 11). Background levels away from waste piles ranged from 12 to 15 μR/hr. The highest reading at the waste pile was 170 μR/hr, and several high readings were found about 145° east of north, 15 meters from the water tank. The average of the shielded gamma dose readings on the waste pile was 80 ± 35 μR/hr. Field readings north of the waste pile area tended to be elevated, reading from 21 to 40 μR/hr. To the south, readings ranged from ambient background levels up to 23 μR/hr.

EPA COLORADO WALK THROUGH

Six mines in the Uravan, Colorado, area and four in the Boulder, Colorado, region were visited briefly. During a walk-through inspection, these mines were cursorily surveyed for gamma activity at 1 meter elevations. Gamma survey maps of these mine areas are given in Figures 12 through 21.

POISON CANYON AREA #2 NEW MEXICO

GAMMA SURVEY - APRIL 1979

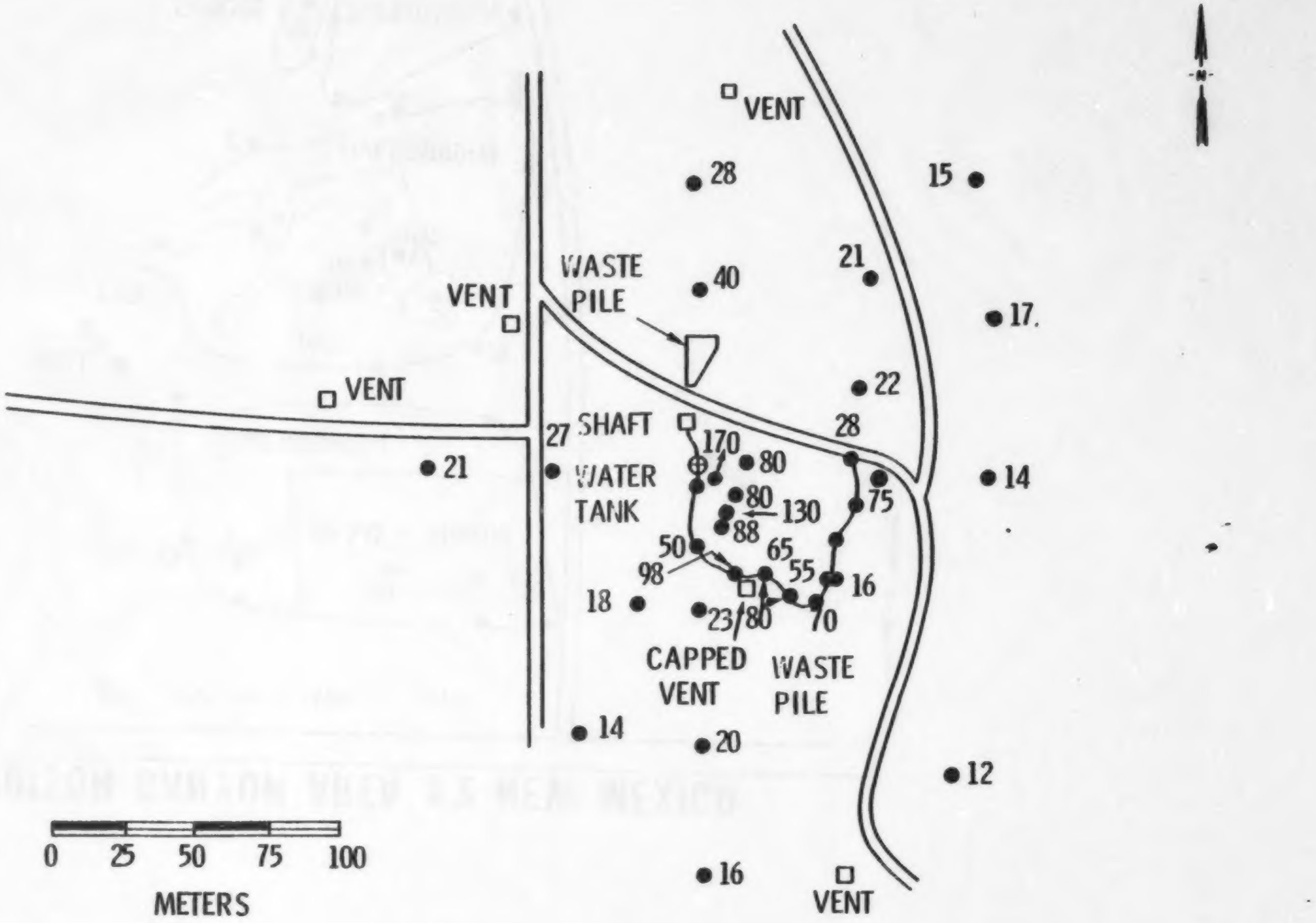


25
65
90
65
250
WASTE + SUBORE
OVERBURDEN
WELL
30
32
40
25
28
PIT
TREE
50
SUBORE
65
190
35
40
40
75
OVERBURDEN
25
25
30
SUBORE
55
OVERBURDEN
ORE
N
GAMMA READINGS - SHIELDED (µR/hr)
0
25
50
75
100
METERS

FIGURE 10

BARBARA J NEW MEXICO

GAMMA SURVEY-APRIL 1979


VENT
28
15
21
40
WASTE
PILE
VENT
17.
22
VENT
27
SHAFT
170
28
21
80
14
WATER
TANK
80
130
75
88
50
65
98
55
16
18
23/80
70
CAPPED
VENT
WASTE
PILE
14
20
12
0
25
50
75
100
METERS
16
VENT

GAMMA READING SHIELDED (μR/hr)

FIGURE 11

Uravan Area

Mine 1. This mine (Figure 12) has a vertical shaft which is barricaded against livestock; however, it is open to the atmosphere. About 14,000 cubic meters of mine wastes were dumped on a downslope area adjacent to the shaft and present cover an area of about 40,000 square meters. Wind and water erosion of the wastes is occurring. Exposure rates, measured 1 meter above the wastes, ranged from 140 to 170 R/hr with several spots reaching 250 R/hr. Several small adjacent waste piles had exposure rate of 110 μR/hr. No springs or standing water were observed near the wastes.

Mine 2. This rim mine (Figure 13) faces the San Miguel River valley and produced about 1,200 cubic meters of wastes which were dumped down the canyon wall and cover an area of about 0.16 km^2. Exposure rates made near the dump point were about 200 μR/hr and measurements on the road around the ore bins ranged from 50 to 150 μR/hr. The mine entry is open to the atmosphere. Wind and water erosion of the mine wastes is occurring.

Mine 3. This mine (Figure 14) has an incline entry which is open to the atmosphere. Two waste piles were built up in order to support ore bins. About 40,000 cubic meters of wastes are contained in the two piles and have a surface area of about 0.65 km^2. Part of the waste piles extends into an adjacent wash and is subject to water erosion. Wind erosion of the wastes is also evident. Gamma exposure rates on the waste piles range from 120 to 150 μR/hr, while areas adjacent to the piles were about 160 μR/hr. The exposure rate on the mine access road was 80 μR/hr.

Mine 4. This is a rim mine with an open entry. The mine waste volume is about 6,000 cubic meters covering an area of about 0.16 km^2 (Figure 15). The wastes have been eroded down the slope through a drain pipe under the highway and into the San Miguel River. Exposure rates on the access road and under the ore bins are about 70 μR/hr. Wind erosion of the wastes is evident.

Mine 5. This mine contains a vertical shaft which is presently being used for forced ventilation of connecting mines (Figure 16). About 75,000 cubic meters of wastes were scattered over an area of about 2 km^2. They were later consolidated into two piles which cover about 0.48 km^2. Gamma

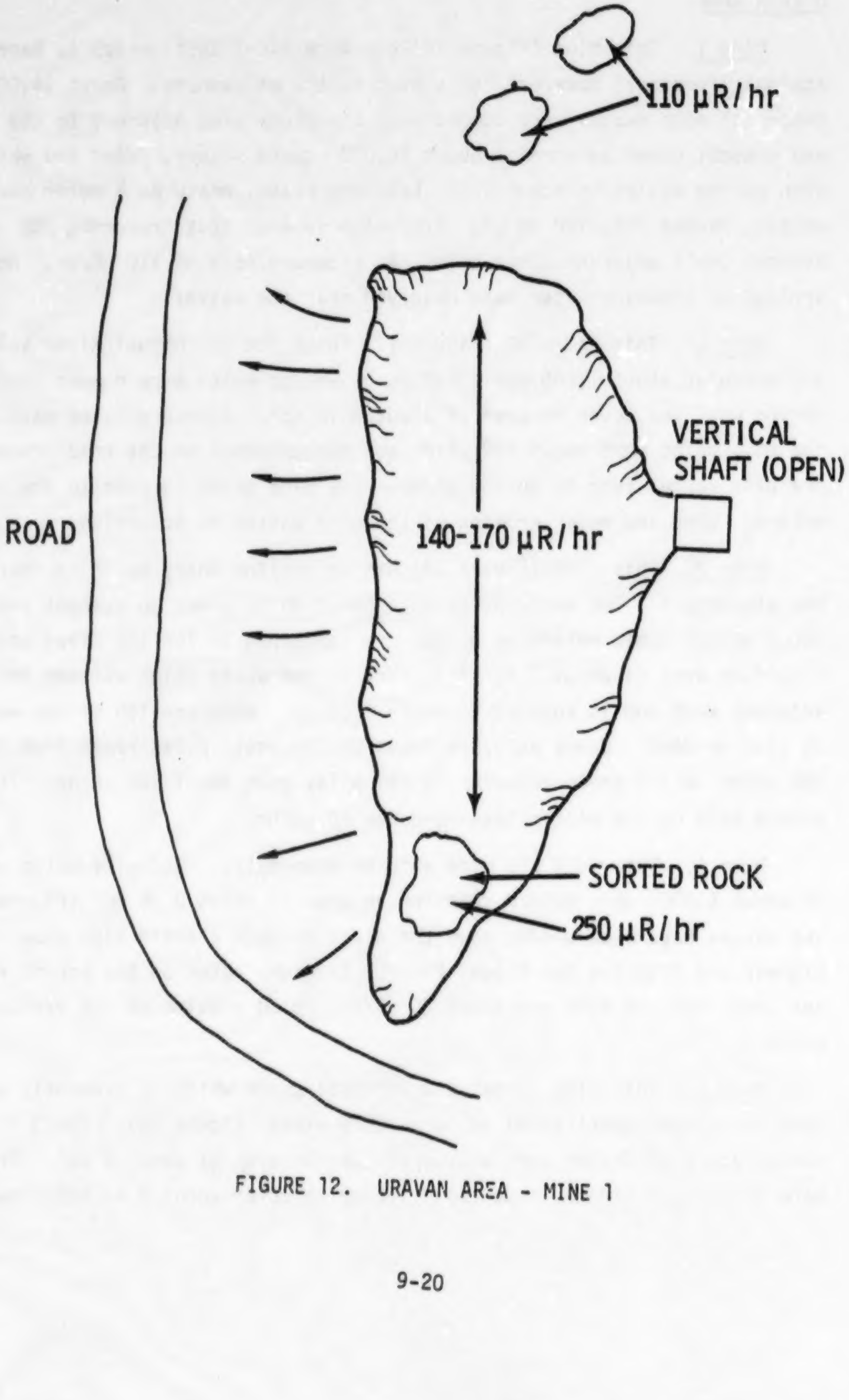

110 µR/hr
VERTICAL SHAFT (OPEN)
ROAD
140-170 µR/hr
SORTED ROCK
250 µR/hr

FIGURE 12. URAVAN AREA - MINE 1

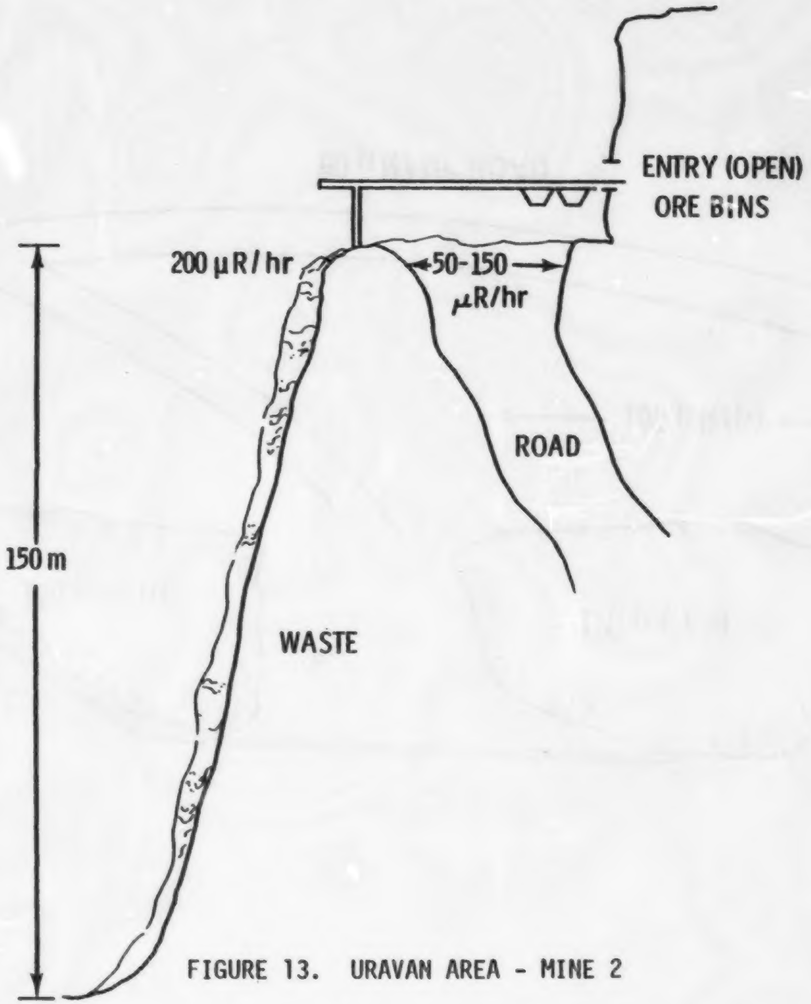

ENTRY (OPEN)
ORE BINS
200 μR/hr
50-150 μR/hr
ROAD
150 m
WASTE

FIGURE 13. URAVAN AREA - MINE 2

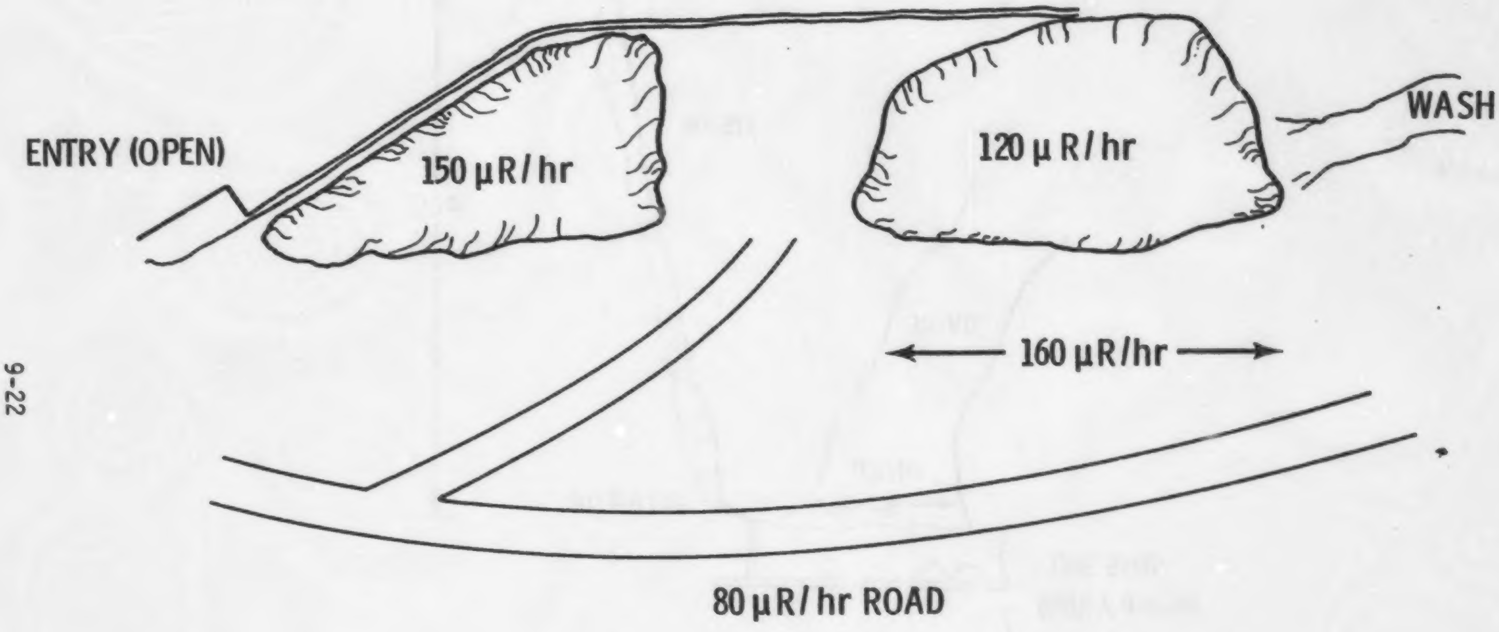

ENTRY (OPEN)
150 µR/hr
120 µR/hr
WASH
160 µR/hr
80 µR/hr ROAD

FIGURE 14. URAVAN AREA - MINE 3

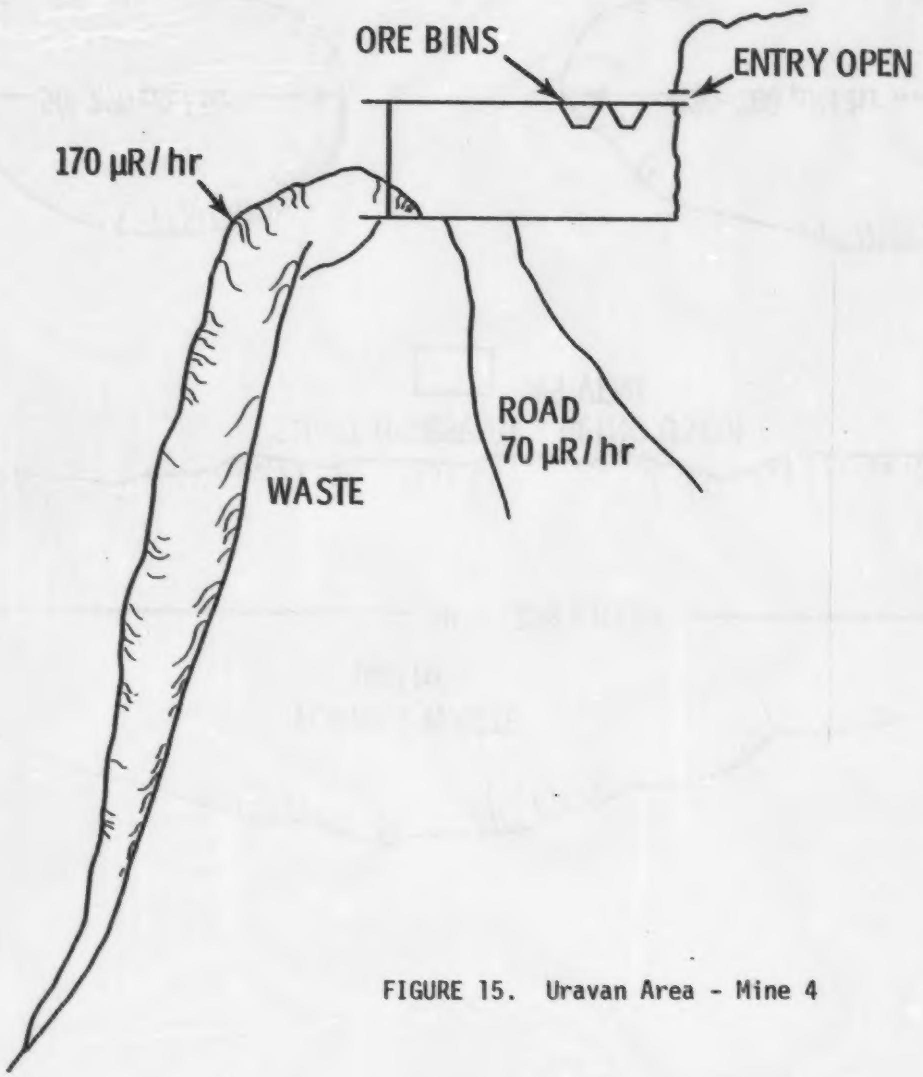
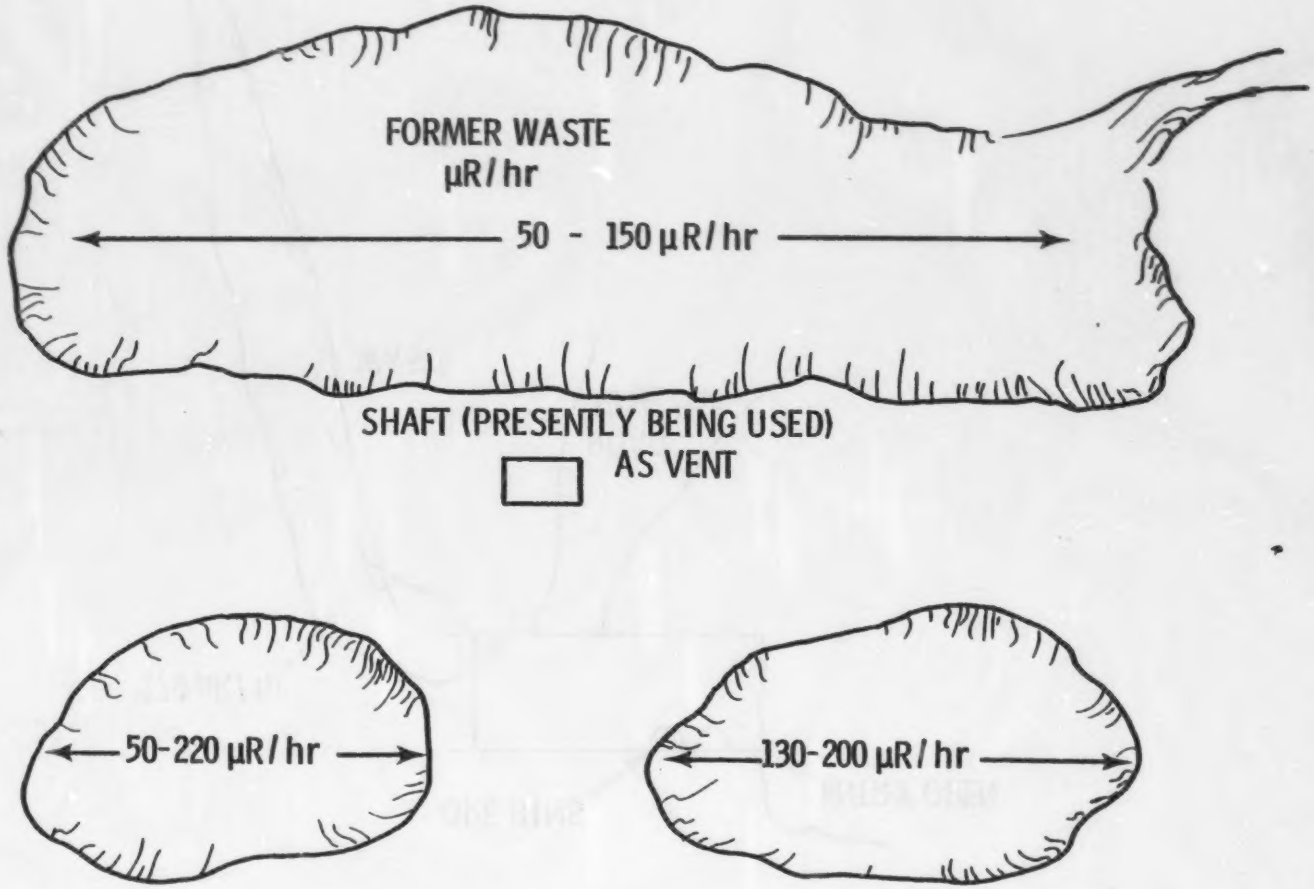

ORE BINS
ENTRY OPEN
170 μR/hr
ROAD
70 μR/hr
WASTE

FIGURE 15. Uravan Area - Mine 4


FORMER WASTE
μR/hr
50 - 150 μR/hr
SHAFT (PRESENTLY BEING USED)
AS VENT
50-220 μR/hr
130-200 μR/hr

NOTE: WASTES FROM FORMER WASTE AREA CONSOLIDATED INTO TWO PILES

FIGURE 16. Uravan Area - Mine 5

exposure rates over the former waste area ranges from 50 to 150 μR/hr. Exposure rates over the consolidated piles range from 50 to 200 μR/hr. Wind and water erosion is evident at both the former and present waste storage areas.

Mine 6. This mine has a vertical shaft which is presently being used to force ventile connecting active mines (Figure 17). About 45,000 cubic meters of wastes were dumped on a downslope adjacent to the mine shaft covering 0.16 km^2 of ground. Gamma exposure rates measured over the waste pile ranged from 180 to 200 μR/hr. Runoff and wind erosion of the wastes are evident. Some of the runoff appears to be entering a nearby stock pond.

Boulder Area

Mine 7. This mine (Figure 18) is relatively small and produces high-grade ore. About 35 cubic meters of wastes remain around the shaft and produce gamma exposure rates of 400 μR/hr. Erosion of the wastes into the nearby wash is evident. Wind erosion is probably minimal. The mine shaft is open and filled with water.

Mine 8. This mine (Figure 19) was principally a fluorspar producer; however, uranium ore was also produced and sold. The mine shaft is open to the atmosphere. Mine wastes adjacent to the shaft occupy about 40,000 m^2. The volume of wastes is estimated to be about 1600 m^3. Gamma exposure rates on the waste pile range from 60 to 80 μR/hr. Extensive water erosion of the wastes is occurring producing exposure rates below the waste piles ranging from 40 to 100 μR/hr. Wind erosion of the wastes is probably minimal.

Mine 9. This mine (Figure 20) is adjacent to the highway just south of Jamestown, Colorado. The mine entry has been covered by a landslide. About 450 m^3 of wastes are present on the site and occupy an area of about 16,000 km^2. Exposure rates near the entry are about 100 μR/hr and range from 40 to 60 μR/hr near the highway.

Mine 10. This mine (Figure 21) is relatively small and has an open entry. Exposure rates near the entry range from 100 to 600 μR/hr. Exposure rates on the mine access road are about 70 μR/hr. Piles containing mine wastes occupy about 32,000 km^2 with a volume of 150 m^3. Water and wind erosion of the wastes is evident.

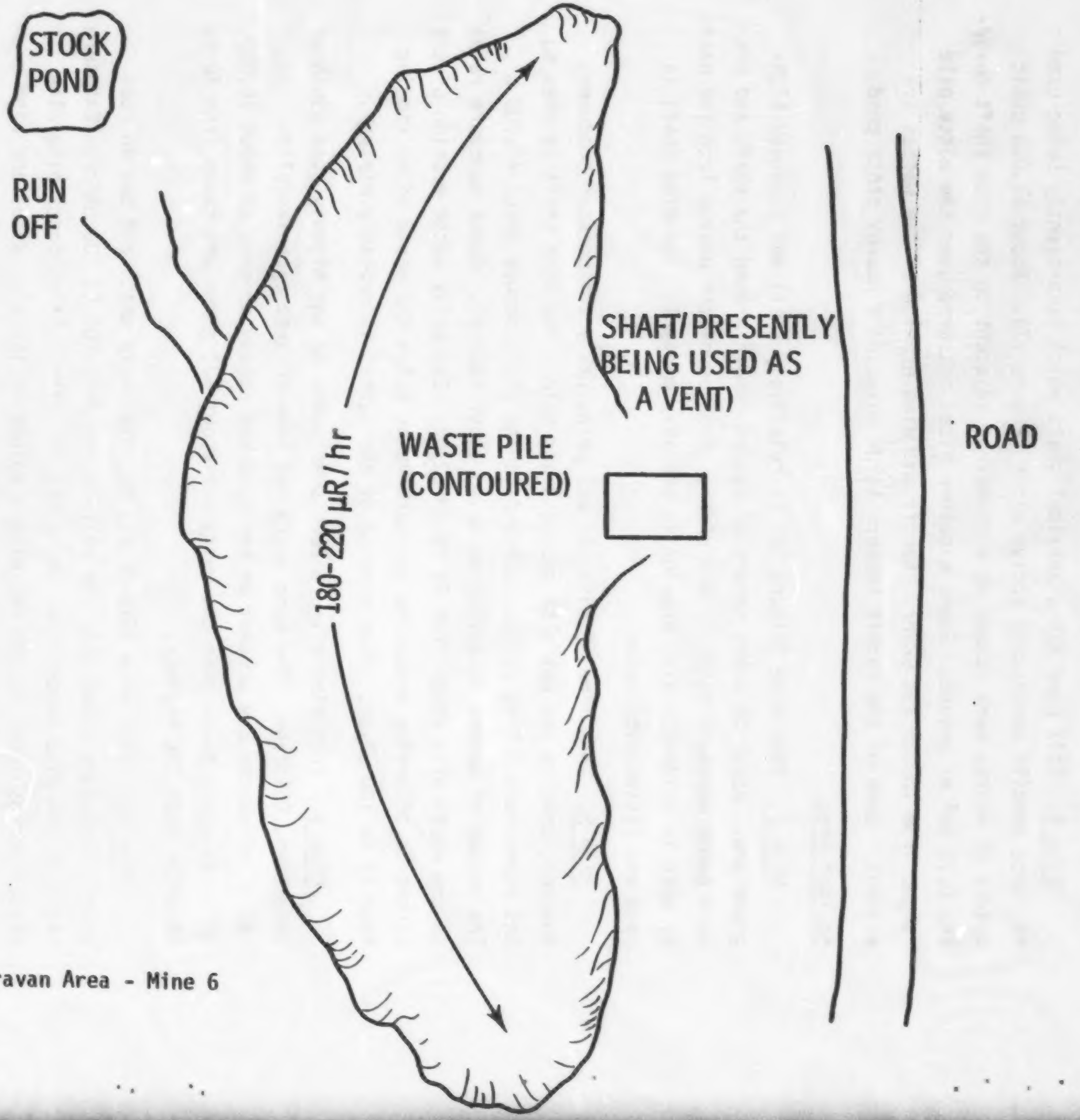

STOCK POND
RUN OFF
SHAFT/PRESENTLY BEING USED AS A VENT)
ROAD
WASTE PILE (CONTOURED)
180-220 μR/hr

FIGURE 17. Uravan Area - Mine 6

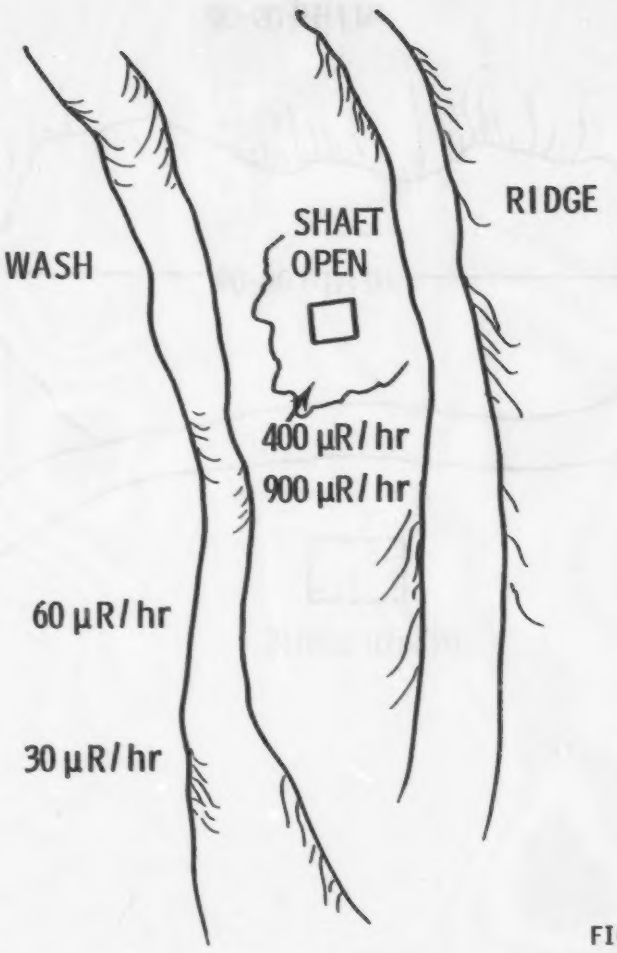

RIDGE
SHAFT
OPEN
WASH
400 μR/hr
900 μR/hr
60 μR/hr
30 μR/hr

FIGURE 18. Boulder Area - Mine 7

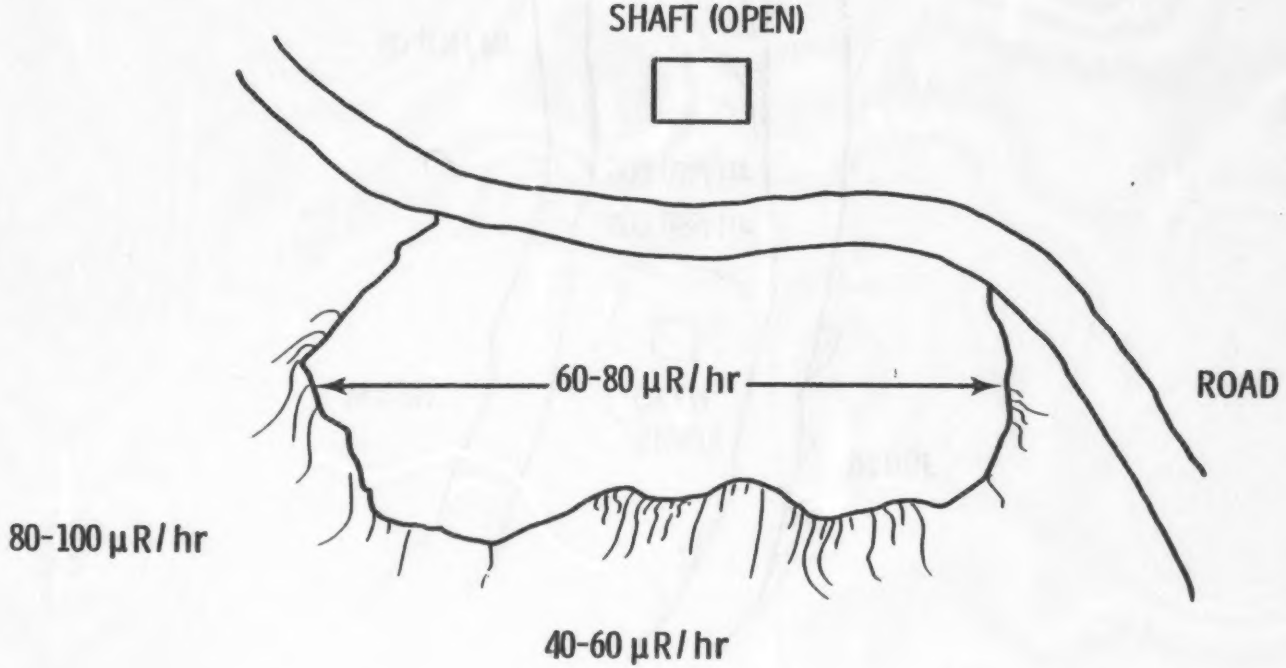

SHAFT (OPEN)
60-80 μR/hr
ROAD
80-100 μR/hr
40-60 μR/hr

FIGURE 19 - Boulder Area - Mine 8

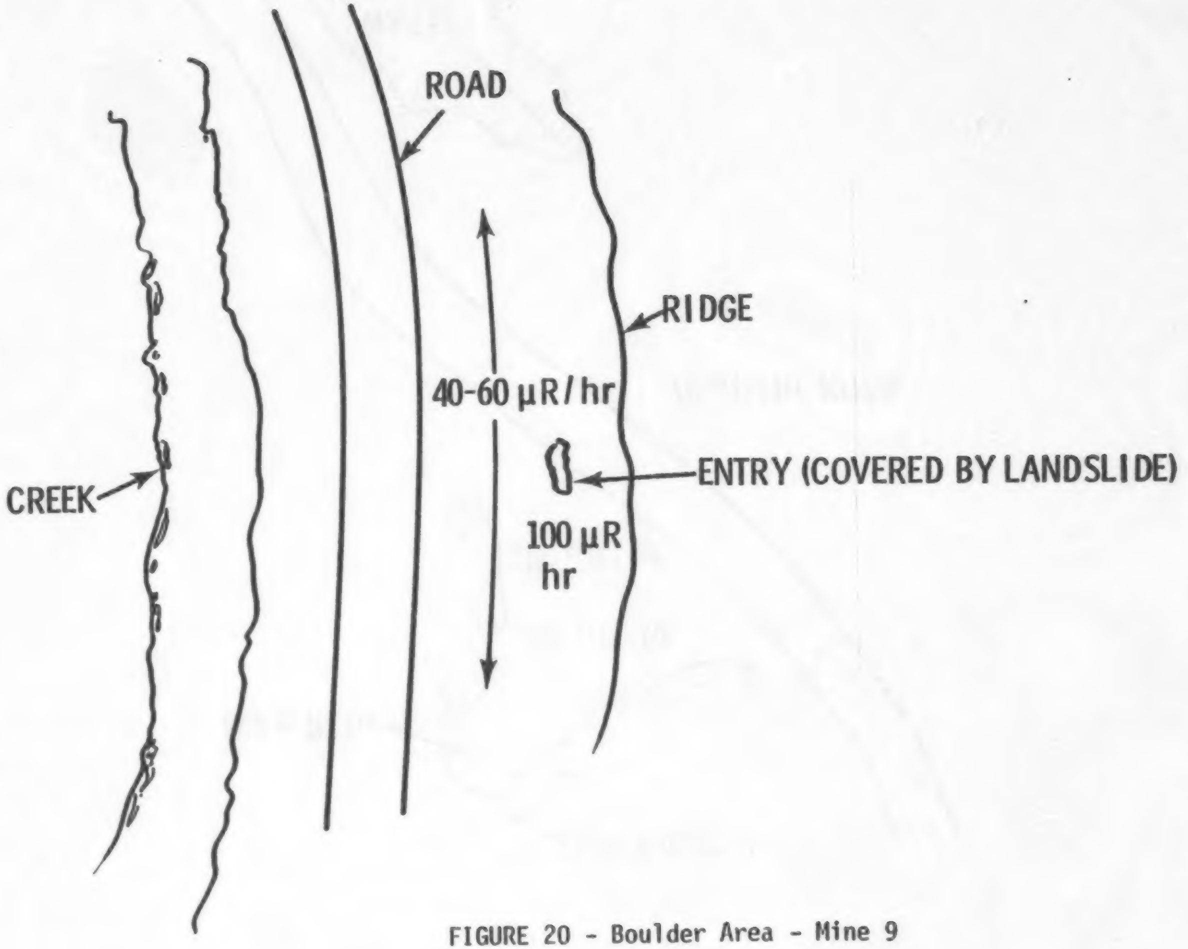
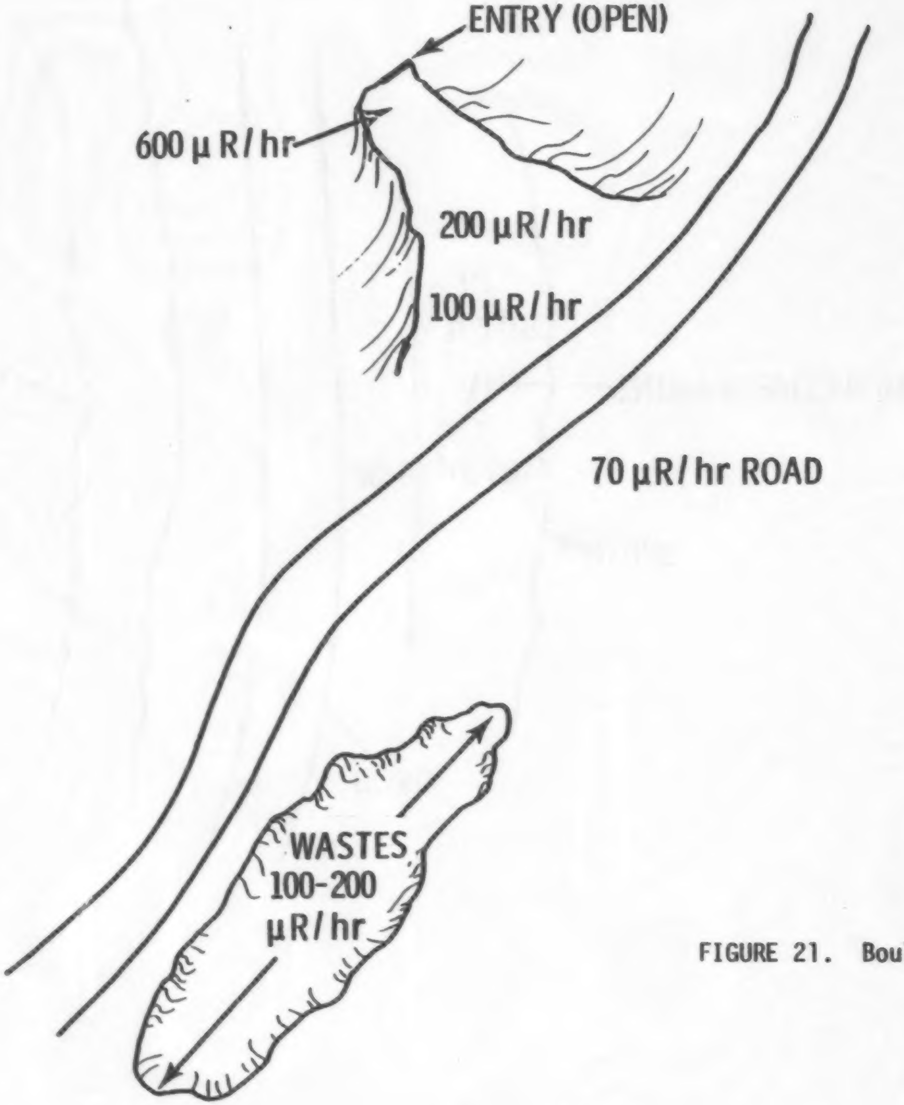

ROAD
RIDGE
40-60 μR/hr
ENTRY (COVERED BY LANDSLIDE)
CREEK
100 μR
hr

FIGURE 20 - Boulder Area - Mine 9



ENTRY (OPEN)
600 µR/hr
200 µR/hr
100 µR/hr
70 µR/hr ROAD
WASTES
100-200
µR/hr

FIGURE 21. Boulder Area - Mine 10

SUMMARY

Gamma surveys of inactive uranium mines were conducted using an NE-148 scintillometer and a pressurized ion chamber (PIC) obtained from the EPA-Las Vegas group. Six inactive uranium mine areas were studied which include Morton Ranch, Wyoming, and the San Mateo, Mesa Top, Poison Canyon Area #1, Poison Canyon Area #2, and Barbara J #3, New Mexico. Also included in this section are measurements made by walk-through at ten inactive mines in the Colorado area by the Environmental Protection Agency personnel.

At the Morton Ranch mine, the gamma survey showed decreasing dose levels as one moved outward from the mine. On some sectors, there was a dose increase as one moved away from the inactive mine which was related to natural outcroppings of uranium ore. In this area, radioactivity is associated with natural outcroppings rather than contamination associated with any mining operation, wind erosion, or wind/water transport of ore material for any distance. A comparison was made of radon flux measured at the Morton Ranch site in Part II, Tasks 6 and 7, with the gamma survey completed in this study. It was rather surprising that the ratio of dose in μR/hr to radon flux varied almost 100-fold. This would indicate that μR readings do not provide a good indication of the radon flux in this area of open pit inactive uranium mines. Shielded dose readings ranged from 11.5 μR/hr to 60 μR/hr away from the inactive pit. Dose readings in the pit varied from 17.5 μR/hr to 68 μR/hr.

The gamma dose survey of the San Mateo mine area indicated that the main waste pile ranged from 35 to 300 μR/hr with heap leach ponds varying from 95-170 μR/hr and a south entry road reading from 13-118 μR/hr. The gamma dose field readings diminished steadily with distance from the waste pile area in the San Mateo mine region with background readings obtained 460 meters from the pile.

Gamma dose measured at the Mesa Top mine ranged from a low of 25 μR/hr at the edge of the waste to a high of 290 μR/hr on the subore pile.

The Poison Canyon #1 mine area had dose readings ranging from 50-165 μR/hr with backgrounds of 25 μR/hr. At the Poison Canyon #2 mine area, most gamma dose readings were approximately 30 ± 5 μR/hr. The surveys indicated local hot spots within the pit and waste site areas. Most readings adjacent

to the pits and waste piles were within a factor of 2 of background levels. At the Barbara J mine site, background levels away from the waste piles ranged from 12-15 μR/hr. The highest readings on the waste piles were 170 μR/hr.

Those mines surveyed in the Uravan area are probably typical of the many inactive uranium mines in the area. Most of the mines are relatively small and are underground. Wind and water erosion is occurring at all of the mines inspected and all of the entries were open except where noted.

Ore haulage losses have occurred on the roads. In addition, mine wastes have been used for road ballast. The ore losses and mine wastes used on the roads probably became airborne as some of the large quantities of dust produced by ore hauling equipment. The lands in the mining area are used for grazing. Some enhanced uptake of radioactive materials and trace metals by cattle is probably occurring.

Exploratory drilling is abundant in the survey area and the resulting land damage is extensive. Little or no reclamation of drill sites was observed.

Three mines were surveyed near Jamestown, Colorado. These mines, although small, are prevalent in this area. Although uranium was not principally produced by many of the mines, the mine wastes are generally radioactive.

Mine wastes were used as fill for the Jamestown Park (34 km^2) and are producing exposure rates of 40 to 110 μR/hr in that area. Some evidence indicates that some dwellings may be built on or near the mine wastes. Surface and groundwater contamination from the mining activities is likely.

RECOMMENDATIONS

Not applicable.

TASK 10

SOIL SAMPLING

INTRODUCTION

Soil sampling for trace element and radionuclide analysis was done to initiate a data base for the Uranium Mill Tailings Radiation Control Act. An attempt was made to collect soils from the inactive sites at Morton Ranch, Wyoming, and in New Mexico at the Poison Canyon mine areas, Barbara J mine, and San Mateo mine. An attempt was made to collect samples of both surface soil and soil as a function of depth. The soil sampling attempted to emphasize areas where erosional movement of soil material would be expected.

The radionuclide analysis was completed with multidimensional gamma-ray spectrometry at Pacific Northwest Laboratory as discussed in the Appendix. Trace element analysis of the soils was completed with X-ray fluorescence technology and instrumental neutron activation analysis as discussed in the Appendix.

EXPERIMENTAL PROTOCOL

Soil samples were collected at the various mines being studied in order to characterize the waste constituents both on and adjacent to these sites. Waste constituents included both radionuclides and trace elements. Radionuclide determinations of ^{234}U, ^{235}U, ^{238}U, ^{230}Th, ^{232}Th, and ^{228}Th were done by EPA at their Las Vegas facility where most of the soil samples were inventoried and split. An aliquot of each sample to be analyzed was then shipped to Pacific Northwest Laboratory for gamma counting of ^{228}Th, ^{208}Tl, ^{226}Ra, and ^{40}K activity and for trace element determinations of potassium, sulfur, chlorine, phosphorus, calcium, titanium, vanadium, chromium, manganese, iron, nickel, copper, zinc, gallium, arsenic, selenium, bromine, rubidium, strontium, yttrium, zirconium, niobium, molybdenum, antimony, cerium, barium, mercury, lead, and uranium by X-ray fluorescence, and sodium, magnesium, aluminum, potassium, calcium, scandium, titanium, vanadium, chromium, manganese, iron, cobalt, arsenic, bromine, rubidium, zirconium, antimony, cesium, barium, lanthanium, cerium, neodymium, samarium, europium, terbium, ytterbium, lutetium, hafnium, tantalum, thorium, and uranium by instrumental neutron activation analysis. Samples are identified throughout this task by their EPA number and their PNL number, both of which are identified with their sample descriptions in Table 1. As indicated in Table 1, many of the New Mexico samples were not logged by EPA number but were shipped directly to Pacific Northwest Laboratory for analysis without being inventoried, split, or analyzed in Las Vegas.

Soil samples usually consisted of surface grab samples, extending on the order of 10 cm in depth and having a mass on the order of a kilogram. Sets of vertical profile samples were obtained by pounding a 5-cm high steel sample scoop into successive vertical increments of the wall of a ~1 meter deep trench dug for this purpose. Soil from each level was carefully removed in order to avoid cross-contamination. Fifteen fractions weighing ~2 kg each were collected in each profile, of which up to five fractions were selected for analysis.

DISCUSSION

Analytical results for all radionuclide analyses by EPA-LV and PNL are collected in Table 2. The analysis of ^{228}Th by both laboratories permits a comparison of this result from two independent methods. Based on the 36 samples analyzed for ^{228}Th, the PNL data are lower than the EPA-LV data by a mean factor of 0.79 ± 0.50, indicating some uncertainty to be present, and a possible bias of about 20%. Since the PNL radionuclide data are reported on a wet weight basis, moisture could account for the bias. The sealed samples are still available for future moisture determinations.

Analyses of ^{234}U and ^{238}U agree remarkably well, within a ratio of 1.1 ± 0.3 for the 29 Morton Ranch samples, and 1.0 ± 0.1 for the nine New Mexico samples. In most samples, especially those for undisturbed areas, uranium was in equilibrium with its daughters as evidenced by ^{226}Ra/^{238}U ratios. Disequilibrium was apparent in individual samples from the alluvial fan (66, 69, 70), top alluvium (61), and erosional channel leading from the 1601 pit at Morton Ranch (71, 72, 73), and the two waste piles at the Poison Canyon area (93, 94) as shown in Table 3. The effects of leaching are evident in looking at the data for the soil profiles, where a radium/uranium average ration of 0.9 was observed in the subsurface (undisturbed) fractions of the top alluvium profile, while a corresponding subsurface mean of 11.7

TABLE 1

SAMPLE DESCRIPTORS

Correlated to Their PNL and EPA Identification Numbers

PNL #	EPA #	Area	Descriptor
61	203741	Morton Ranch	Soil profile, composite 41 m, 370 m and top alluvium at 1601 pit
62	203742	Morton Ranch	Top alluvium, profile, #3 1601 pit
63	203743	Morton Ranch	Top alluvium, profile, #6 1601 pit
64	203744	Morton Ranch	Top alluvium, profile, #12 1601 pit
65	203745	Morton Ranch	Top alluvium, profile, #15 1601 pit
66	203746	Morton Ranch	Alluvial fan, profile, #1 1601 pit
67	203747	Morton Ranch	Alluvial fan, profile, #3 1601 pit
68	203748	Morton Ranch	Alluvial fan, profile, #6 1601 pit
69	203749	Morton Ranch	Alluvial fan, profile, #12 1601 pit
70	203750	Morton Ranch	Alluvial fan, profile, #13 1601 pit
71	203751	Morton Ranch	Erosional drainage, 180 m from 1601 pit
72	203752	Morton Ranch	Erosional drainage, 370 m from 1601 pit
73	203753	Morton Ranch	Erosional drainage, 570 m from 1601 pit
74	203754	Morton Ranch	Erosional drainage, 1200 m from 1601 pit, at gate
78	203758	Morton Ranch	S. Box Creek sediment, 90 m above $BaCl_2$ outlet
75	203755	Morton Ranch	S. Box Creek sediment, 310 meters downstream of 1704 pit
79	203759	Morton Ranch	S. Box Creek sediment, above 1601 pit pond area
76	203756	Morton Ranch	S. Box Creek sediment, SWS-4 at lease boundary
77	203757	Morton Ranch	Box Creek sediment, SWS-6, downstream from N-S Box Creek junction
83	203771	Morton Ranch	Bottom alluvium, profile, #1 1704 pit
84	203772	Morton Ranch	Bottom alluvium, profile, #3 1704 pit
85	203773	Morton Ranch	Bottom alluvium, profile, #6 1704 pit
86	203774	Morton Ranch	Bottom alluvium, profile, #12 1704 pit
87	203775	Morton Ranch	Bottom alluvium, profile, #15 1704 pit
80	203760	Morton Ranch	Top soil piles 1 and 2, composite 1601
81	203761	Morton Ranch	Soil composite, NE 148A $\Delta=4$
82	203762	Morton Ranch	Soil composite, NE 148A $\Delta=8$
88	203777	Morton Ranch	Spoil pile #3, subore
89	203776	Morton Ranch	Ore, composite of #1, 2, 3, and 4 piles

Table 1 - Sample Descriptors (continued)

PNL #	EPA #	Area	Descriptor
90	203763	Poison Canyon	Area #1, bench
91	203764	Poison Canyon	Area #1, pit floor
92	203765	Poison Canyon	Area #1, terrace
93	203766	Poison Canyon	Area #1, waste pile #1
94	203767	Poison Canyon	Area #1, waste pile #2
95	203768	Poison Canyon	Area #1, background soil
96	203769	Barbara J #1	Waste pile composite
97	203770	Barbara J #1	Background soil
98	------	San Mateo	Waste pile composite soil
99	------	San Mateo	Waste pile composite rocks
100	------	San Mateo	Waste drainage stream bed soil
101	------	San Mateo	Waste drainage stream bed soil, 60 m downstream
102	------	San Mateo	Background soil, 60 m up site gully
103	------	San Mateo	Main gully soil, 200-300 m downstream
104	------	San Mateo	Main gully soil, 400-500 m downstream
105	------	San Mateo	Side gully soil, gully near heap leach
106	------	San Mateo	Heap leach soil composite
107	------	San Mateo	Heap leach rock composite
108	------	San Mateo	Mud from San Mateo Creek below mine
109	------	San Mateo	Mud from San Mateo Creek above mine
110	------	Poison Canyon	Mine drainage 5, inside gully above mine drainage
111	------	Poison Canyon	Mine drainage 4, further downstream (C)
112	------	Poison Canyon	Mine drainage 3, further downstream (B)
113	------	Poison Canyon	Mine drainage 2, downstream from mine (A)
114	------	Poison Canyon	Mine drainage 1, 200 m upstream from mine
115	------	Poison Canyon #2	North rim overburden
116	------	Poison Canyon #2	Pit floor, red earth
117	------	Poison Canyon #2	Waste and subore pile
118	------	Poison Canyon #2	From matrix containing ore
118-a	------	Poison Canyon #2	Ore sample from ore matrix

TABLE 2

RADIONUCLIDE CONCENTRATIONS IN SOILS
(pCi/g)

MORTON RANCH

	EPA						PNL			
Sample Number	^{234}U	^{235}U	^{238}U	^{228}Th	^{230}Th	^{232}Th	^{228}Th	^{208}Tl	^{226}Ra	^{40}K
61 UMS 91101 EPA 203741 Comp. -135-400 m and top - 1601	172±19	6.9±1.1	189±21	2.06±.41	161±6	1.51±.35	.86	0.31	77	15
62 UMS 91102 EPA 203742 1601 Top Alluvium #3 Profile	1.7±0.3	.068±.040	1.6±.3	1.12±.16	2.4±.2	0.65±.12	.75	0.27	1.9	22
63 UMS 91103 EPA 203743 1601 Top Alluvium #6 Profile	2.3±.3	.095±.044	2.1±.3	1.85±.19	1.9±.2	1.71±0.17	1.44	0.52	1.5	13
64 UMS 91104 EPA 203744 1601 Top Alluvium #12 Profile	1.2±0.2	.074±.042	1.3±0.2	1.34±.16	0.9±0.1	1.14±.15	1.00	0.38	1.0	14
65 UMS 91105 EPA 203745 1601 Top Alluvium #15 Profile	1.7±0.3	.076±.043	1.4±.3	1.74±.17	1.3±.2	1.11±.13	1.25	0.45	1.1	15
66 UMS 91106 EPA 203746 Alluvial Fan #1 1601 Top Profile	11.8±1.4	0.82±.23	11.0±1.4	1.58±.25	31.4±1.6	1.58±.25	1.03	0.37	39.0	15
67 UMS 91107 EPA 203747 Alluvial Fan #3 1601 Profile	6.0±0.8	0.22±.10	5.4±0.8	1.47±.26	18.0±.9	0.90±.21	1.03	0.37	11.3	17

TABLE 2 (Continued)

RADIONUCLIDE CONCENTRATIONS IN SOILS
(pCi/g)

MORTON RANCH

	EPA						PNL			
Sample Number	^{234}U	^{235}U	^{238}U	^{228}Th	^{230}Th	^{232}Th	^{228}Th	^{208}Tl	^{226}Ra	^{40}K
68 UMS 91108 EPA 203748 1601 Alluvial Fan #6 Profile	2.4±4	0.099±.046	1.9±.3	1.35±.16	2.9±.2	0.95±.12	0.94	0.34	3.2	20
69 UMS 91109 EPA 203749 1601 Alluvial Fan #12 Profile	19.6±2.7	0.45±.22	11.0±1.7	2.15±.43	23.8±7.1	3.08±.52	1.25	0.45	223	---
70 UMS 91110 EPA 203750 1601 Alluvial Fan #15 Profile	14.6±2.2	0.27±.18	5.7±1.0	1.97±.39	481±14	3.50±.56	0.64	0.23	508	---
71 UMS 91111 EPA 203751 1601 Erosional Channel from 1601 - 180 m	7.4±0.9	0.31±.06	7.2±0.9	1.25±.13	23.2±0.9	1.11±.11	1.39	0.50	38	4
72 UMS 91112 EPA 203752 1601 Erosional Channel from 1601 - 370 m	1.9±0.3	0.080±.03	1.9±0.2	1.33±.12	3.7±0.2	1.33±.12	1.14	0.41	4.0	19
73 UMS 91113 EPA 203753 1601 Erosional Channel from 1601 - 579 m	1.7±0.2	0.11±.04	1.8±0.2	1.31±.12	3.5±.2	1.00±.10	1.08	0.39	4.5	10

TABLE 2 (continued)

RADIONUCLIDE CONCENTRATIONS IN SOILS

(pCi/g)

MORTON RANCH

Sample Number	EPA						PNL			
	^{234}U	^{235}U	^{238}U	^{228}Th	^{230}Th	^{232}Th	^{228}Th	^{208}Tl	^{226}Ra	^{40}K
74 UMS 91114 EPA 203754 1601 Erosional Channel @ Gate	1.5±0.2	.082±.031	1.6+.2	0.78±.09	1.9±.1	0.73±.08	0.67	0.24	2.0	18
75 UMS 91115 EPA 203755 340 m downstream from 1704	1.0±.2	.036±.019	1.0±.2	1.25±.11	1.4±.1	1.31±.12	1.03	0.37	1.1	23
76 UMS 91116 EPA 203756 SWS 4 @ lease Boundary near 1601	1.6±.2	.062±.027	1.5±.2	0.57±.07	1.0±.1	0.42±.06	0.56	0.20	1.0	13
77 UMS 91117 EPA 203757 SWS 6 @ junction of N-S Box Creek	1.0±.2	.042±.028	0.9±0.1	0.66±.07	0.7±.1	0.59±.07	0.86	0.31	1.1	22
78 UMS 91118 EPA 203758 SWS 2 100 yds above back outlet	0.4±.1	.033 ±.018	0.4±0.1	0.44±.07	0.3±.1	0.25±.05	0.14	0.05	0.3	21
79 UMS 91119 EPA 203759 W-6 Drainage above 1601 pond	7.2±0.9	.33±06	7.5±.9	1.94±.12	3.3±0.2	1.25±0.10	2.02	0.73	6.6	9
80 UMS 91120 EPA 203760 Top Soil Piles 2 & 1 Composite	1.5±0.2	4.1±1.6	1.5±0.2	1.33±.12	3.3±0.2	1.40±.13	0.80	0.29	2.7	11

TABLE 2 (continued)

RADIONUCLIDE CONCENTRATIONS IN SOILS
(pCi/g)

MORTON RANCH

	EPA						PNL			
Sample Number	^{234}U	^{235}U	^{238}U	^{228}Th	^{230}Th	^{232}Th	^{228}Th	^{208}Tl	^{226}Ra	^{40}K
81 UMS 91121 EPA 203761 Composite Delta 4	1.7±0.2	.067±.028	1.6±0.2	1.04±.10	1.7±0.1	0.87±.09	1.17	0.42	1.8	17
82 UMS 91122 EPA 203762 Composite Delta 8	1.7±.2	.091±.031	1.6±.2	0.33±.04	2.7±.2	0.61±.07	1.11	0.40	3.4	20
83 UMS 91123 EPA 203771 1704 Soil Profile Bottom Alluvium #1	3.2±0.4	.10+.04	3.3±.5	1.58±.17	5.6±.9	1.49±.16	—	—	8.9	6
84 UMS 91124 EPA 203772 1704 Soil Profile Bottom Alluvium #3	2.7±0.5	.15±.09	2.7±0.5	1.61±.27	7.8±.7	.72±.19	0.56	0.20	15	11
85 UMS 91125 EPA 203773 1704 Soil Profile Bottom Alluvium #6	2.9±.4	.15±.04	2.7±.3	1.16±.10	1.4±.1	1.12±.10	0.86	.31	1.4	12
86 UMS 91126 EPA 203774 1704 Soil Profile Bottom Alluvium #12	1.8±.3	.08±.03	2.0±.3	1.62±.15	1.6±.1	1.44±.13	1.06	0.38	1.4	15
87 UMS 91127 EPA 203775 1704 Soil Profile Bottom Alluvium #15	3.3±.4	.16±.05	3.5±.5	1.5±.1	1.5±.1	1.46±.12	0.88	0.32	1.5	10

MORTON RANCH

TABLE 2 (continued)

RADIONUCLIDE CONCENTRATIONS IN SOILS

(pCi/g)

	EPA						PNL			
Sample Number	^{234}U	^{235}U	^{238}U	^{228}Th	^{230}Th	^{232}Th	^{228}Th	^{208}Tl	^{226}Ra	^{40}K
88 UMS 91129 EPA 203777 Spoil Pile #3 Sub Ore	21.6±2.6	.43±.16	23.7±2.8	1.54±.26	12.9±.8	1.13±.21	1.07	0.39	23	16.0
89 UMS 91128 EPA 203776 Ore Composite Piles 1,2,3&4	173±19	7.7±1.4	192±21	2.30±.44	225±9	1.47±.37	1.58	0.5	180	1.0

TABL 2 (continued)

RADIONUCLIDE CONCENTRATIONS IN SOILS
(pCi/g)

Poison Canyon Area #1

		EPA						PNL			
	Sample Number	^{234}U	^{235}U	^{238}U	^{228}Th	^{230}Th	^{232}Th	^{228}Th	^{208}Tl	^{226}Ra	^{40}K
90	UMS 91093 EPA 203763 Bench Area #1	40.5 ± 5.7	1.71 ± .29	40.8 ± 4.7	0.45 ± .06	28.7 ± .8	0.46 ± .06	0.39	0.14	43	6.4
91	UMS 91094 EPA 203764 Area #1 Pit Floor	12.6 ± 1.5	0.56 ± .10	13.7 ± 1.6	0.50 ± .06	11.6 ± .3	0.41 ± .06	0.39	0.14	15	7.2
92	UMS 91095 EPA 203765 Area #1 Terrace	4.2 ± 0.5	0.17 ± .04	4.2 ± 0.5	0.56 ± .07	6.3 ± .3	0.56 ± .07	0.42	0.15	7	11
93	UMS 91096 EPA 203766 Waste Pile #1	6.5 ± 0.8	0.46 ± .11	7.5 ± 0.9	0.62 ± .11	9.7 ± .5	0.45 ± .09	0.44	0.16	86	7
94	UMS 91097 EPA 203767 Waste Pile #2	16.8 ± 2.0	0.72 ± .19	16.9 ± 2.0	1.29 ± .25	17.7 ± .9	0.56 ± .16	0.42	0.15	38	11
95	UMS 91098 EPA 203768 Background Soil	1.6 ± 0.2	0.089±.031	1.5 ± 0.2	0.71 ± .08	2.1 ± .1	0.53 ± .07	0.53	0.19	3	13

TABLE 2 (continued)

RADIONUCLIDE CONCENTRATIONS IN SOILS
(pCi/g)

Barbara J #1

Sample Number	EPA						PNL			
	^{234}U	^{235}U	^{238}U	^{228}Th	^{230}Th	^{232}Th	^{228}Th	^{208}Tl	^{226}Ra	^{40}K
96 UMS 91099 EPA 203769 Waste Pile Composite	88.0 ± 9.7	4.30 ± .82	88.0 ± 9.7	1.86 ± .41	62.6 ± 3.1	0.64 ± .23	0.31	0.11	110	3
97 UMS 91100 EPA 203770 Background Soil	1.1 ± 0.2	0.042 ± .021	1.1 ± 0.2	0.43 ± .06	2.0 ± 0.1	0.35 ± .06	0.44	0.16	3	13

was observed in the redeposited material in the alluvial fan area of the same drainage. The surface sample from the top of the fan was much higher in uranium than the lower fractions, possibly due to run-off from the nearby ore piles. However, some of the very large differences in ^{238}U to ^{226}Ra ratios (samples 69 and 70) may simply be due to differences in the composition of sample aliquots analyzed by EPA for ^{238}U versus those analyzed by PNL for ^{226}Ra. Thorium-232/^{238}U ratios averaged 0.5 ± 0.3 for the 29 Morton Ranch samples and 0.2 ± 0.3 for the New Mexico samples. Thorium was nearly constant at 1.4 ± 0.7 pCi/g in Wyoming and 0.5 ± 0.1 pCi/g in New Mexico.

Major and trace element concentrations for 45 elements are tabulated in Tables 4 and 5. Since many elements were simultaneously determined by both X-ray fluorescence and instrumental neutron activation analysis, agreement between the two methods can readily be checked using such elements as iron, calcium, potassium, or barium. Generally good agreement is observed between the two methods, except when concentrations are near the detection limits and counting statistics become poor.

Some of the major element concentrations such as magnesium, aluminum, and potassium are relatively constant among all the soil samples, while others, including sodium, calcium, titanium, and iron, are more varied, indicating the geological differences among the samples. At least some degree of correlation is apparent between uranium and arsenic, molybdenum, lead, and perhaps copper. This is particularly in evidence for the ore sample No. 118a. Uranium was in the 1-5 ppm range in most undisturbed sample areas and indicated mine-related contamination in the soil profiles at the Morton Ranch 1601 pit (230 and 26 ppm U), in the erosional drainage channel (20 ppm U), and in the spoil pile (95 ppm U). Interestingly, the Box Creek sediments downstream from the 1601 and 1704 pit areas show no enhancement of uranium (5 and 2.5 ppm U), indicating water-transported mine wastes to be very strongly localized. An illustration of apparent naturally elevated uranium content in the Box Creek sediments is found above the 1601 pit pond area where the uranium concentration reached 18 ppm. Topsoils at Morton Ranch averaged 3.5 ppm (80, 81, 82).

TABLE 3

URANIUM-238 AND RADIUM-226 CONCENTRATION AND RATIOS AT INACTIVE URANIUM MINING SITES

Material	PNL No.	^{238}U	^{226}Ra	$^{238}U/^{226}Ra$
Top alluvium	61	189	77	2.45
	62	1.6	1.9	0.84
	63	2.1	1.5	1.40
	64	1.3	1.0	1.30
	65	1.4	1.1	1.27
Alluvial fan	66	11.0	30.0	0.37
	67	5.4	11.3	0.48
	68	1.9	3.2	0.59
	69	11.0	223	0.05
	70	5.7	508	0.01
Erosion drainage	71	7.2	38	0.19
	72	1.9	4.0	0.48
	73	1.8	4.5	0.40
	74	1.6	2.0	0.80

TABLE [illegible]

TRACE ELEMENT COMPOSITION OF SOIL, WASTE AND ORE FROM INACTIVE WYOMING AND NEW MEXICO OPEN PIT URANIUM MINES*

(µg/g except as noted)

Sample Location	P (%)	S (%)	Cl (%)	K (%)	Ca (%)	Ti	V	Cr	Mn	Fe (%)	Ni	Cu	Zn	Ga	As
Morton Ranch															
61	<0.6	<0.19	<0.11	2.4	0.96	1800	110	34	205	1.09	19	10	29	12	7.5
62	<0.7	<0.20	<0.09	2.6	0.66	1500	<50	37	120	0.91	19	8	24	10	5.3
63	<0.7	<0.20	<0.10	1.9	0.53	3700	150	52	59	2.37	36	29	90	18	9.1
64	<0.6	<0.19	<0.10	1.9	0.47	3100	130	<29	86	1.96	32	16	70	16	7.5
65	<0.6	<0.18	<0.09	1.9	0.43	3100	70	30	57	1.66	26	15	58	12	8.5
66	<0.7	<0.19	<0.09	2.1	0.69	1700	90	42	130	1.05	14	8	26	11	4.6
67	<0.7	<0.20	<0.09	2.5	0.56	1300	<50	42	94	0.87	20	11	23	12	3.3
68	<0.6	<0.19	<0.10	2.2	0.73	1800	60	25	130	1.24	18	9	29	14	5.2
69	<0.7	<0.19	<0.10	2.3	1.04	1500	120	28	190	0.96	16	5	22	10	4.7
70	<0.7	<0.21	<0.10	2.4	0.62	1100	90	29	72	0.52	8	7	13	9	4.9
71	<0.6	<0.20	<0.09	1.7	0.59	3300	160	37	250	2.28	23	17	85	17	11
72	<0.7	<0.22	<0.10	2.1	0.47	2500	70	52	200	1.24	17	12	36	8	6.8
73	<0.7	<0.20	<0.10	1.7	1.15	3000	100	44	190	2.32	28	21	58	14	6.0
74	<0.7	<0.20	<0.10	2.6	0.65	1600	<50	37	140	1.16	14	11	27	10	4.2
75	<0.7	<0.24	<0.10	2.3	0.30	810	<42	31	114	0.46	18	8	10	7	2.9
76	<0.7	<0.20	<0.09	2.3	0.34	1400	<51	31	100	0.76	11	7	19	9	1.7
77	<0.7	<0.22	<0.10	2.8	0.69	1400	<50	23	107	0.88	15	7	22	11	3.4
78	<0.7	<0.20	<0.10	2.1	0.28	780	<39	<18	70	0.39	13	7	9	6	<1.6
79	<0.5	0.31	<0.08	1.1	1.82	2500	90	71	3390	2.55	26	19	81	15	10
80	<0.7	<0.21	<0.10	2.2	0.49	2300	60	46	190	1.34	21	13	37	11	3.2
81	<0.7	<0.20	<0.09	2.1	0.47	2100	100	43	180	1.19	14	8	33	9	3.9
82	<0.7	0.21	<0.09	2.1	0.46	2100	70	<24	180	1.15	15	12	32	9	5.6
83	<0.6	<0.17	<0.09	1.8	0.46	2800	130	42	120	1.66	19	11	45	14	5.6
84	<0.6	0.20	<0.09	2.2	0.52	1600	70	<23	110	0.94	16	9	23	10	3.7
85	<0.6	<0.19	<0.09	1.7	0.55	2900	130	45	210	1.82	16	17	60	15	6.2
86	<0.7	<0.20	<0.10	2.0	0.52	3100	90	63	270	2.24	24	16	58	12	8.8
87	<0.7	<0.20	<0.10	2.1	0.51	3000	70	51	350	2.09	24	19	67	13	5.7
88	<0.7	0.25	<0.11	2.3	0.66	2900	<100	<36	140	1.16	18	9	25	11	<1.8
89	<0.7	<0.21	<0.10	2.3	0.62	1500	200	<27	180	1.05	17	9	25	11	5.4

*Measured by X-ray fluorescence analysis

TABLE 4 (tinued)

TRACE ELEMENT COMPOSITION OF SOIL, WASTE AND ORE FROM INACTIVE WYOMING AND NEW MEXICO OPEN PIT URANIUM MINES*

(µg/g except as noted)

Sample Location	Se	Br	Rb	Sr	Y	Zr	Nb	Mo	Sb	Ce	Ba	Hg	Pb	U
Morton Ranch														
61	17	<1	85	95	17	140	7.4	<2.7	<4	51	760	<5	14	140
62	1.2	<1	100	97	10	84	3.9	3.5	<3	38	720	<5	17	<6
63	<1	<1	111	115	41	250	13	2.5	<3	160	470	<5	21	<7
64	1.9	<1	100	104	24	240	11	4.2	<3	72	550	<5	14	<7
65	<1	<1	86	94	22	280	8.5	6.2	<5	65	590	<5	14	<7
66	2.7	<1	81	94	12	150	6.7	<2.0	<3	38	690	<5	17	21
67	1.1	1.1	89	94	9	95	3.7	3.8	<3	27	760	<5	17	<6
68	<1	<1	92	99	11	108	3.7	2.1	4	27	770	<5	17	<7
69	1.3	2.4	86	95	27	130	3.5	<1.9	<3	34	560	<5	18	13
70	<1	<1	89	88	7	101	2.1	<1.8	4	56	730	<4	14	8
71	2.5	1.4	102	101	20	210	13	<2.2	<3	42	800	<5	23	16
72	<1	2.1	85	90	15	240	8.2	<1.7	<3	62	760	<4	19	<5
73	<1	4.3	91	105	18	250	10	3.4	4	56	530	<5	20	<6
74	<1	1.4	98	111	10	97	4.8	<1.7	<3	35	810	<5	17	<7
75	<1	<1	88	77	8	60	3.9	4.9	<3	37	690	<4	18	<5
76	<1	1.3	88	87	9	85	3.3	1.8	<3	31	750	<4	23	<6
77	<1	1.2	103	112	9	87	2.1	<1.7	<3	29	720	<4	17	<6
78	<1	<1	76	81	7	67	2.3	7.2	<3	22	750	<4	23	<5
79	7	31	85	197	19	170	11	<2.2	<4	72	550	<5	26	11
80	<1	1.2	98	89	17	190	6.9	2.9	<3	61	700	<4	23	6
81	<1	<1	87	90	14	200	7.6	2.5	5	58	680	<4	25	<6
82	<1	<1	92	90	14	210	6.0	2.8	3	46	570	<5	20	<7
83	1.3	<1	94	103	19	230	11	2.9	5	66	701	<5	22	<7
84	1.1	<1	89	93	10	115	5.7	4.4	3	43	693	<4	16	<6
85	1.4	2.2	94	105	20	270	11	3.2	4	66	591	<5	24	<6
86	1.1	2.9	102	96	19	230	9.1	3.5	3	65	618	<4	15	<6
87	1.1	4.2	102	102	21	260	9.4	3.2	<3	72	660	<5	23	<6
88	2.1	<1	75	128	14	150	6.9	<2.2	<3	42	680	10	22	61
89	28	<1	69	94	17	116	5.2	<2.9	<3	43	800	<7	16	370

TABLE 4 (continued)

TRACE ELEMENT COMPOSITION OF SOIL, WASTE, AND ORE FROM INACTIVE WYOMING AND NEW MEXICO OPEN PIT URANIUM MINES

(μg/g except as noted)

Sample Location	P (%)	S (%)	Cl (%)	K (%)	Ca (%)	Ti	V	Cr	Mn	Fe (%)	Ni	Cu	Zn	Ga	As
Poison Canyon #1															
90	1.0	0.30	<0.09	1.1	17.6	2100	80	<30	310	0.79	9	11	21	7	7.0
91	<0.9	<0.23	<0.09	1.1	19.6	2100	<70	<27	340	0.70	11	11	18	5	5.4
92	0.8	0.24	<0.09	1.4	13.2	2300	<60	<27	280	0.87	12	10	24	8	4.7
93	<0.8	0.21	<0.09	1.4	14.5	2200	<70	<28	260	0.75	9	11	23	7	7.8
94	<0.8	<0.21	<0.09	1.6	10.3	2100	<60	<26	220	1.00	9	13	25	8	3.0
95	<0.7	<0.21	<0.10	1.8	2.4	1800	<50	<23	200	0.89	10	12	22	7	4.1
Barbara J															
96	1.2	0.29	<0.06	0.53	24	1900	180	<43	750	0.72	18	21	23	5	14
97	<0.7	<0.21	<0.10	1.6	0.90	1600	<50	<20	190	0.76	7	9	19	4	2.3
San Mateo															
100	<0.8	<0.24	<0.10	1.7	0.14	2013	78	<23	176	0.9	<6	8	19	5	3.1
101	<0.6	<0.17	<0.08	1.8	0.16	2018	114	<23	179	1.1	10	9	24	7	5.1
103	<0.8	<0.22	<0.10	1.5	0.10	1723	<50	<23	191	1.3	12	9	20	6	6.2
104	<0.6	<0.16	<0.08	1.4	0.52	1254	<42	27	146	0.79	9	6	20	7	3.6
105	<0.7	<0.19	<0.09	1.8	0.11	2111	<52	<23	186	1.2	8	10	26	7	3.8
108	<0.7	<0.22	<0.10	1.9	0.70	1800	55	<22	157	0.93	11	10	24	7	5.2
109	<0.7	<0.21	<0.09	1.8	0.68	1829	<51	<24	152	0.85	8	12	26	7	2.2
Poison Canyon Mine Drainage															
110	<0.8	<0.21	<0.09	1.2	0.86	1195	<61	<25	264	0.57	8	8	11	4	4.0
111	<0.6	<0.17	<0.08	1.4	0.26	988	<44	<16	190	0.55	6	5	11	5	<1.6
112	<0.6	<0.17	<0.08	1.4	0.20	1247	<44	<19	191	0.66	<5	7	14	5	2.0
113	<0.7	<0.19	<0.09	1.2	0.17	1168	<44	<16	167	0.50	11	7	10	3	<1.4
114	<0.7	<0.20	<0.08	1.4	0.34	903	<46	<19	244	0.44	10	7	9	4	1.5

TABLE 4 (continued)

TRACE ELEMENT COMPOSITION OF SOIL, WASTE AND ORE FROM INACTIVE WYOMING AND NEW MEXICO OPEN PIT URANIUM MINES

(μg/g except as noted)

Sample Location	Se	Br	Rb	Sr	Y	Zr	Nb	Mo	Sb	Ce	Ba	Hg	Pb	U
Poison Canyon #1														
90	2.7	<1	45	127	12	213	4.7	<2.0	<3	25	390	<6	12	44
91	<1	<1	41	111	10	143	3.6	<2.1	<3	21	380	<5	10	16
92	<1	2.0	53	98	9	214	4.3	2.5	<3	27	390	<5	15	<6
93	<1	<1	49	99	9	187	3.9	2.5	<3	24	540	<5	10	8
94	<1	<1	58	159	11	193	6.8	<2.1	4	29	460	<5	11	25
95	<1	1.4	61	72	9	260	4.8	5.5	<3	26	450	<4	12	<5
Barbara J														
96	3.1	<2	32	178	9	98	<2.1	<2.8	<3	14	280	<8	31	189
97	<1	1.5	59	50	8	260	4.2	4.9	<3	26	440	<4	13	<5
San Mateo														
100	3.9	<1	62	86	12	232	7.4	2.0	2	35	566	<4	15	42
101	3.7	1.4	70	110	14	230	9.2	<2.2	4	44	484	<5	13	53
103	1.2	<1	61	87	8	119	6.2	2.9	<2	26	383	<4	8	<4
104	<1	<1	66	78	9	209	6.7	2.9	<3	34	434	<4	11	<6
105	<1	2.6	75	102	12	259	7.8	4.0	3	43	517	<4	15	<5
108	<1	1.1	83	106	11	131	7.6	2.3	<2	40	597	<4	13	<5
109	<1	<1	76	112	12	150	7.3	3.6	3	39	695	<4	16	<5
Poison Canyon Mine Drainage														
110	<1	<1	46	102	7	141	2.4	2.7	4	26	1826	<4	9	<5
111	<1	<1	54	77	7	134	<1.5	4.2	<3	20	791	<4	15	<6
112	<1	<1	54	74	9	271	3.7	4.5	<3	23	609	<4	10	<6
113	<1	<1	48	68	8	219	2.7	0.9	4	23	853	<4	10	<5
114	<1	<1	60	79	5	113	<1.3	4.3	<3	29	1277	<4	9	<5

TABLE 4 (continued)

TRACE ELEMENT COMPOSITION OF SOIL, WASTE, AND ORE FROM INACTIVE WYOMING AND NEW MEXICO OPEN PIT URANIUM MINES

(μg/g except as noted)

Sample Location	P (%)	S (%)	Cl (%)	K (%)	Ca (%)	Ti	V	Cr	Mn	Fe (%)	Ni	Cu	Zn	Ga	As
Poison Canyon #2															
115	<0.7	<0.18	<0.09	1.6	0.29	1706	55	<22	197	0.91	9	10	21	7	2.1
116	<0.7	<0.18	<0.09	1.8	0.86	2900	102	<30	473	2.0	11	13	45	12	5.5
117	1.7	0.43	<0.40	0.112	34.4	1100	<55	<51	446	0.2747	17	22	13	<4	4.1
118	0.73	0.33	<0.40	0.154	27.6	1100	<55	<48	673	0.3840	15	27	14	6	6.0
118a*	--	--	<0.20	<0.1	36.0	313	370	<60	295	0.38	<12	40	6	6	46.0

*118a. This is a selected ore sample from the ore-soil matrix material.

TABLE 4 (continued)

TRACE ELEMENT COMPOSITION OF SOIL, WASTE AND ORE FROM INACTIVE WYOMING AND NEW MEXICO OPEN PIT URANIUM MINES

(μg/g except as noted)

Sample Location	Se	Br	Rb	Sr	Y	Zr	Nb	Mo	Sb	Ce	Ba	Hg	Pb	U
Poison Canyon #2														
115	<1	<1	62	95	9	200	5.0	<1.9	<3	29	489	<4	14	<5
116	1.2	5.5	77	203	19	218	9.3	<2.6	<4	60	562	<6	19	10
117	<1.4	<1.2	10	179	4.5	42	1.7	<1.8	<7	<14	45	<6	25	57
118	1.5	<1.2	16	323	4.6	15	2.1	<1.8	<8	<16	64	<6	31	<6
118a*	<3.3	<5	<18	236	<2	50	<6	217	--	--	--	<17	262	8023

*118a. This is a selected ore sample from the ore-soil matrix material.

TABLE 5

TRACE ELEMENT COMPOSITION OF SOIL, WASTE AND ORE FROM INACTIVE WYOMING AND NEW MEXICO OPEN PIT URANIUM MINES*

(µg/g except as noted)

SAMPLE	Na (%)	Mg (%)	Al (%)	K (%)	Ca (%)	Sc	Ti (%)	V	Cr	Mn	Fe (%)	Co	As	Br	Rb	Zr	Sb	Cs	Ba	La	Ce	Nd	Sm	Eu	Tb	Yb	Lu	Hf	Ta	Th	U
203741-61	0.99	0.2	4.8	2.0	1.1	4.1	0.20	140	32	190	1.0	5.4	4.3	0.86	80	100	0.26	1.3	780	22	60	40	13	0.70	0.40	1.7	0.2	3.7	0.50	7.0	230
203742-62	1.03	0.2	4.8	2.2	0.61	2.8	0.10	30	20	150	0.80	3.4	2.8	1.0	80	100	0.20	1.2	720	14	25	10	2.2	0.53	0.26	1.3	0.23	3.4	0.28	4.5	3.4
203743-63	0.11	0.2	7.3	2.0	0.60	10	0.34	100	60	100	2.2	9.2	5.0	0.75	100	250	0.90	6.3	500	51	100	50	8.6	2.0	1.0	4.1	0.60	6.3	1.1	14	6.0
203744-64	0.26	0.5	5.6	1.9	0.45	7.1	0.34	70	50	110	1.7	8.3	5.6	0.40	90	280	0.60	3.8	560	28	60	24	4.5	1.1	0.63	3.1	0.45	7.4	0.80	11	3.5
203745-65	0.39	0.2	4.8	1.9	0.44	5.7	0.30	60	40	100	1.3	9.3	5.0	0.40	70	280	0.48	2.3	(8600)	29	60	23	4.4	0.95	0.55	2.6	0.40	7.8	0.64	11	3.6
203746-66	1.00	0.8	4.8	2.1	0.67	3.3	0.20	60	40	180	1.0	5.8	3.4	0.60	90	150	0.22	1.1	720	17	35	22	1.1	0.50	0.30	1.3	0.2	4.4	0.60	9.1	26
203747-67	1.02	0.2	5.0	2.5	0.54	3.4	0.10	30	44	100	0.74	3.4	3.4	1.0	90	150	0.21	0.94	720	15	30	16	2.1	0.54	0.27	1.3	0.30	3.2	0.35	5.8	7.0
203748-68	1.41	0.5	5.4	2.5	0.60	4.4	0.14	30	50	140	1.0	5.8	3.5	0.80	90	140	0.16	0.60	740	15	24	15	2.3	0.46	0.22	1.0	0.20	4.0	0.30	9.7	3.8
703749-69	1.18	0.2	6.4	2.0	1.1	3.3	0.14	120	23	190	0.92	7.9	3.4	2.7	70	100	0.22	0.67	800	18	40	21	5.1	0.64	0.32	1.5	0.3	4.1	0.50	5.7	28
203750-70	1.17	0.2	4.8	2.8	0.63	2.8	0.10	130	25	90	0.76	31	7.4	1.7	110	100	0.19	0.48	730	18	32	16	2.4	0.40	0.27	1.1	0.2	2.8	0.75	9.3	18
203751-71	0.43	0.5	6.6	1.9	0.58	9.8	0.30	110	65	300	2.3	11	7.0	2.0	100	230	0.78	4.9	630	30	55	30	5.0	0.85	0.55	2.3	0.3	6.2	0.83	12	20
203752-72	0.91	0.2	4.5	2.7	0.48	4.3	0.20	70	35	200	1.1	5.3	4.5	1.0	100	220	0.40	2.0	800	18	35	16	2.9	0.70	0.40	2.1	0.30	6.8	0.52	8.2	4.0
203753-73	0.48	0.5	6.0	1.8	1.0	8.1	0.26	80	50	190	2.2	9.6	7.0	4.6	90.	270	0.63	3.7	600	27	50	23	4.1	0.95	0.50	2.5	0.40	6.2	0.80	11	4.2
203754-74	1.12	0.5	5.2	2.7	0.60	2.6	0.14	30	20	140	0.86	3.1	2.4	1.7	90	100	0.22	1.2	810	12	20	13	1.8	0.48	0.21	1.0	0.20	2.1	0.30	4.5	4.4
203755-75	0.96	0.8	3.6	2.3	0.25	1.2	0.06	30	10	110	0.33	1.4	1.3	0.80	90	90	0.080	0.45	700	19	27	10	2.4	0.32	0.26	1.1	0.16	3.1	0.17	9.2	2.0
203756-76	0.99	0.7	4.2	2.1	0.31	3.0	0.10	30	34	140	0.82	3.1	2.7	1.7	80	150	0.21	1.1	740	18	30	13	2.0	0.53	0.30	1.6	0.30	3.9	3.2	5.6	5.0
203757-77	1.06	0.2	4.9	2.7	0.64	3.1	0.10	30	20	150	0.90	3.9	3.0	1.6	100	90	0.22	1.2	760	12	20	10	1.9	0.40	0.22	1.0	0.17	2.9	0.47	4.8	2.6
203758-78	1.08	0.3	3.8	2.1	0.31	1.1	<0.1	<10	10	70	0.36	1.4	1.6	0.70	80	60	0.12	0.33	730	8.6	13	8.0	1.2	0.30	0.15	0.70	0.10	1.8	0.10	2.7	1.2
203759-79	0.27	0.4	6.4	1.4	1.7	11	0.30	80	66	3500	2.8	15	10	32	90	170	0.75	4.7	590	27	55	30	4.5	0.76	0.44	2.0	0.3	5.0	0.70	12	18
203760-80	0.90	0.2	5.1	2.0	0.46	4.7	0.27	50	40	210	1.3	5.5	4.0	2.0	90	220	0.38	2.2	700	20	34	16	3.1	0.58	0.40	1.7	0.27	5.9	0.46	7.3	3.5
203761-81	0.78	0.3	4.6	1.9	0.60	5.0	0.21	50	48	180	1.3	5.4	4.6	1.5	85	200	0.40	2.0	610	18	33	16	2.8	0.58	0.50	2.1	0.30	7.0	0.48	8.0	3.5
203762-82	0.54	0.3	5.0	2.3	0.47	4.7	0.20	60	40	180	1.2	5.7	5.0	1.4	94	200	0.43	2.0	690	20	35	18	3.0	0.63	0.38	1.7	0.27	6.4	0.46	10	3.6
203771-83	0.60	0.3	5.3	2.0	0.69	6.6	0.27	70	47	180	1.6	7.5	4.7	1.0	100	250	0.50	3.2	660	24	43	20	3.7	0.67	0.48	2.0	0.40	7.0	0.74	9.3	8.0
203772-84	0.84	0.5	5.8	2.1	0.44	4.9	0.20	70	30	140	1.1	6.0	3.6	1.4	100	150	0.40	2.3	700	24	50	22	3.6	0.77	0.38	1.7	0.40	4.7	0.55	7.1	8.5
203773-85	0.50	0.5	5.2	1.9	0.64	7.2	0.28	70	90	300	1.8	8.3	6.0	3.7	90	240	0.72	3.6	620	26	50	24	4.1	0.76	0.49	2.0	0.35	6.3	0.68	9.6	7.3
203774-86	0.56	0.6	5.6	2.1	0.52	7.7	0.24	70	60	270	2.1	8.4	6.0	2.7	100	200	0.57	2.5	640	25	44	23	4.0	0.77	0.51	2.1	0.34	6.3	0.66	10	4.8
203775-87	0.59	0.6	5.8	2.1	0.49	6.9	0.28	80	50	350	2.1	7.9	5.2	4.1	90	300	0.58	3.5	700	28	58	24	4.7	0.95	0.58	2.7	0.40	7.0	0.80	10	8.0
203777-88	1.20	0.5	5.0	2.1	0.92	5.5	0.3	60	60	170	1.2	13	2.7	0.40	80	150	0.61	0.80	710	18	25	20	1.6	0.60	0.30	1.3	0.2	4.6	0.30	7.2	95
203776-89	1.15	0.7	5.0	2.2	1.1	3.2	0.2	180	16	240	0.80	4.2	3.5	0.45	80	200	0.24	0.70	760	20	60	60	30	0.55	0.28	1.3	0.3	2.4	0.25	7.0	400
203763-90	0.23	0.5	3.0	1.2	12.0	2.8	0.2	100	15	360	0.72	3.2	5.2	1.1	50	200	0.36	1.4	400	10	25	17	2.4	0.40	0.24	1.1	0.2	6.5	0.25	3.5	40
203764-91	0.21	0.8	3.2	1.1	12.0	2.6	0.20	40	10	350	0.60	2.9	5.9	1.9	44	150	0.36	1.4	510	10	30	11	4.6	0.48	0.26	1.2	0.3	4.3	0.30	3.1	30
203765-92	0.25	0.4	3.1	1.3	10.2	2.7	0.20	40	13	300	0.70	2.9	5.2	2.3	50	270	0.36	1.6	480	11	25	10	2.1	0.48	0.26	1.3	0.3	6.0	0.35	3.5	12
203766-93	0.15	0.4	2.9	1.2	10.2	2.6	0.2	40	11	290	0.75	2.5	5.0	0.60	46	180	0.32	1.3	490	10	24	11	3.3	0.45	0.25	1.2	0.4	5.7	0.35	3.2	18
203767-94	0.22	0.5	3.5	1.4	9.5	3.0	0.2	70	10	260	0.92	2.8	2.0	0.45	54	200	0.28	1.6	520	12	34	14	5.6	0.48	0.26	1.4	0.2	5.1	0.36	3.5	45
203768-95	0.47	0.7	2.2	1.4	1.3	2.7	0.2	40	14	170	0.85	2.5	3.5	2.1	55	300	0.40	1.8	540	13	30	12	2.3	0.46	0.30	1.5	0.30	7.8	0.36	4.0	4.2
203769-96	0.27	0.4	2.0	0.89	19.7	1.7	0.2	130	13	510	0.48	2.5	10	1.0	35	150	0.31	1.0	340	10	40	30	2.3	0.35	0.21	1.0	0.2	3.0	0.20	1.7	270
203770-97	0.40	0.2	2.7	1.3	0.60	2.0	0.2	30	11	200	0.74	1.9	2.7	1.7	51	240	0.36	1.4	480	12	24	10	2.0	0.42	0.24	1.3	0.25	6.3	0.35	3.6	3.5

* ESTIMATED ERRORS BASED ON COUNTING STATISTICS ARE: ±0.5 - 5% FOR Na, Al, Sc, Mn, Fe, Co, La, Sm AND Yb; ±5 - 10% FOR K, Ca, Ti, V, Cr, As, Br, Rb, Sb, Cs, Ba, Eu, Hf, Ta, Th AND U; ±10 - 20% FOR Mg, Zr, Ce, Nd, Tb AND Lu. VALUES IN PARENTHESIS ARE SUSPECT OF CONTAMINATION. UPPER LIMITS ARE BASED ON 3σ VALUE.

*Measured by Instrumental Neutron Activation Analysis

Soils in the Poison Canyon area, New Mexico, contained ~4.2 ppm U, waste piles were in the 18-45 ppm U range, and soils in the open pit ranged from 12-36 ppm U. Using the X-ray fluorescence data for Poison Canyon Area #2, uranium varied highly from <5 ppm in overburden to 10 ppm U in the pit floor. No uranium was detected above the 5 ppm level in any of the mine drainage areas at the Poison Canyon site. Stream beds in the San Mateo, New Mexico, area all contained <5 ppm U, except the drainage bed adjacent to the waste pile, which contained 42 ppm, and the same stream bed at 60 meters downstream, which contained 53 ppm U. Vanadium and selenium were also elevated in these two samples, apparently also originating from the waste piles.

Other elements which may potentially indicate pollution show no apparent correlation with mine activities. Chromium, which was generally higher at Morton Ranch than in New Mexico, was <27 and <36 ppm in the ore and spoil composites, but was usually in the 30-70 ppm range in most of the soil, overburden, and drainage area samples. Manganese showed a similar lack of correlation to mining, but was extremely elevated (3400 ppm) in the South Box Creek sediment above the 1601 pit pond area, possibly indicating an unusual mineral deposit there. This value was confirmed at 3500 ppm in the activation analysis (Table 4). Nickel varied from 8-36 ppm at Morton Ranch, and from <5-18 ppm in New Mexico. Copper, zinc, and arsenic had normal ranges of 7-29 ppm, 9-90 ppm, and <2-14 ppm, respectively. The highest arsenic value was observed at the Barbara J waste pile (96), and in ore sample 118a which suggests that arsenic may be a mine-related pollutant. Molybdenum varied from <2-217 ppm and lead from 9-272 ppm, and these do show correlation with uranium in the ore sample 118a. Mercury was less than 4-8 ppm in all cases, except spoil pile #3 at Morton Ranch, where 10 ± 4 ppm were observed. This is considered of marginal significance due to its proximity to the detection limit and the absence of mercury detection in any other samples from that area.

SUMMARY

The trace element concentrations at the inactive uranium mining sites show a wide variation in soil and waste rock which is generally unrelated to mining activities. There are, however, some definite correlations between uranium and certain trace elements in ore samples. For example, high uranium concentrations were associated with high concentrations of molybdenum, vanadium, arsenic, and possibly copper. Radionuclide concentrations in environmental soils varied by orders of magnitude as might be expected and seem to be the best indicator of pollution from the mining activities. Uranium-238 to ^{226}Ra ratios differed by as much as 100-fold which seems unreasonably large, and we therefore question whether this reflects inhomogeneity in sample aliquots selected for ^{238}U and ^{226}Ra measurements rather than actual disequilibrium. Except for the specifically selected uranium ore sample, radioactivity in all of the samples was rather small and would therefore not seem to constitute a major environmental contamination problem.

RECOMMENDATIONS

It must be recognized that this study was conducted over a very short period of time and a very limited amount of time was available for the planning and sampling operation, as well as for the analyses. We therefore recommend that these observations be considered as preliminary and that prior to formulation of rigid guidelines for the deactivation of mine sites, more detailed studies of this type should be conducted. These could be based on the information gathered in this work and aimed specifically at determining radionuclide and trace element distribution in the environs of a fairly large active or inactive uranium mining site.

TASK 11

CHEMICAL CONSTITUENTS OF MILL TAILING LEACHATES

INTRODUCTION

A study of the chemical constituents of mill tailing leachates was initiated to provide a data base for the Uranium Mill Tailings Radiation Control Act. Trace elements as well as the radionuclides ^{238}U, ^{230}Th, ^{228}Th, ^{210}Pb, and ^{226}Ra must be measured to evaluate the movement of these species from mill tailings through hydrologic means. Tailings are continually leached by precipitation and the salt solutions residing with processed tailings following both acid and basic leaching of the raw ore material. This brief study sampled tailing influents in both acid and carbonate leach tailings material piles and solutions seeping from the base of these same tailings piles.

EXPERIMENTAL PROTOCOL

Samples of the influent tailings slurry to both the acid and carbonate leach tailings piles in the Grants, New Mexico region were obtained for analysis of chemical and radiochemical constituents. In addition, the samples of solutions seeping from the base of these same tailings piles were also obtained for comparison of the amounts of the constituents which had been lost or gained during percolation through the tailings pile. Following filtration through 0.45 micron Nuclepore filters, trace elements were measured by plasma emission or X-ray fluorescence spectroscopy, and radionuclides by gamma-ray spectrometry using a large intrinsic germanium diode. Measured concentrations of trace elements are given in Table 1, and the radionuclide data in Table 2 for the samples collected during May, 1979. Similar samples were collected several months later and again measured for trace elements and radionuclides. These data are fairly similar and are summarized in Tables 3 and 4.

DISCUSSION

The large tailings piles may be considered as giant heap leach processes where the leach solution is continuously added to the top of the pile and this subsequently moves through the pile extracting uranium and other leachable trace elements. The concentrations of both trace elements and radionuclides were found to be quite variable in the seep solutions and also showed some variation in the actual input slurry from the uranium mills. Major differences were observed in the input slurries from the acid leach versus the alkaline leach slurry solutions. The acid leach slurry contained much larger amounts of the trace elements copper, nickel, zirconium, beryllium, chromium, cadmium, vanadium, calcium, manganese, and iron than the alkaline leach slurry. The basic leach slurry contained higher concentrations of molybdenum, selenium, and uranium and comparable concentrations of arsenic. The input slurry from the acid leach process actually contained about 100-fold greater concentrations of dissolved thorium and ^{210}Pb than the alkaline leach slurry. These differences could have been expected based on the chemistry of these radioelements.

In general, it appears that the seep solutions have concentrations which are comparable to those of the input slurry. There are some exceptions, notably that of uranium from the alkaline leach seep area where its concentration is about ten-fold greater than that in the input slurry. One would predict that there should be higher concentrations of the leachable elements in the solutions that have moved through the tailings piles than that which was present in the input slurry. Also, one would expect that as these leach solutions move from the tailings pile into the underlying soil that the exchange sites within the soil would be saturated and that the solutions reaching the water table would eventually have a composition similar to that of the input slurry. Preliminary analyses of a few samples seem to confirm this assumption.

SUMMARY

The concentrations of the trace elements and radionuclides which are soluble in the tailings slurries from alkaline and acid leach mills have been compared with seep solutions from the respective tailings piles. It was observed that the seep solutions have concentrations which are comparable to those in the input slurries but may actually be higher as a result of the heap leaching process which takes place within the tailings pile. It also appears that as these seep solutions move into the underlying soil, they will quickly saturate the sorption sites in the soil and that the solutions moving into the groundwater table will eventually have a composition similar to that of the input slurry.

RECOMMENDATIONS

We recommend that a study be carried out which would carefully compare the concentrations of dissolved trace elements and radionuclides in input slurries, seepage solutions, and groundwater for active uranium tailings piles from both alkaline leach and acid leach uranium extraction processes.

TABLE 2

RADIONUCLIDE CONCENTRATIONS IN URANIUM TAILINGS SOLUTIONS

(pCi/ℓ)

Sample	^{210}Pb	^{238}U	^{230}Th	^{226}Ra
A. Alkaline Leach Mill				
1. Input Slurry	381	12600	670	161
2. Pond Solution	54	9810	<60	32
3. West Side Seep	236	12100	361	41
4. East Side Seep	120	82700	1160	487
B. Acid Leach Mill				
5. Input Slurry	39800	4990	259000	<240
6. Evaporation Pond	18700	4000	205000	800
7. East Side Seep	490	2380	3970	650
8. West Side Seep	140	9180	26200	160

TABLE 3

TRACE ELEMENTS IN URANIUM MILL EFFLUENT AND IN TAILINGS LEACHATE*

	ppm														
	S	Cl	Ca	V	Mn	Fe	U	Ni**	Cu**	Zn**	Se	Pb	As	Sr	Mo
A. Alkaline Leach Mill	Date: 10/2/79														
1. Input slurry	248	331	< 8.3	5.8	< .88	6.1	49	<.01	.06	<.01	36	<4.2	5.4	<6.4	85
2. East pond solution	286	212	< 8.3	9.9	<1.1	13	46	<.01	.07	<.01	33	<4.2	4.8	<6.7	80
3. West seep	380	<81	<11	<2.9	<1.0	24	170	.08	.15	<.01	9	<2.9	3.1	<6.6	152
4. East seep	604	283	<12	<3.3	1.1	12	405	.08	.12	<.01	5	<3.4	3.3	<7.4	392
B. Acid Leach Mill	Date: 10/3/79														
5. Input slurry	1136	<88	265	71	172	2780	24	1.4	6.2	13	2.5	<4.9	2.6	16	14
6. Evaporation pond	1383	178	103	81	256	2950	22	2.2	6.0	19	2.0	<3.0	4.0	10	14
7. East seep	1117	<87	361	65	168	3000	19	7.5	7.4	12	5.0	<3.9	2.8	10	16

*Analyzed by X-ray fluorescence spectrometry

**Analyzed by plasma emission spectroscopy

TABLE 4

RADIONUCLIDE CONCENTRATIONS IN URANIUM TAILINGS SOLUTIONS COLLECTED IN OCTOBER 1979

pCi/liter

	^{238}U	^{230}Th	^{228}Th
A. Alkaline Leach Mill			
1. Input slurry	23,000	3,650	< 86
2. East pond solution	20,000	810	< 36
3. West seep	84,600	14,600	< 86
4. East seep	157,000	17,700	<160
B. Acid Leach Mill			
5. Input slurry	9,800	367,000	1470
6. Evaporation pond	8,900	333,000	9770
7. East seep	7,200	189,000	4160

TASK 12

CHEMICAL AND RADIOCHEMICAL COMPOSITION OF AIRBORNE PARTICULATES DOWNWIND FROM A URANIUM TAILINGS PILE

INTRODUCTION

Measurements of the chemical and radiochemical composition of airborne particulates blowing from uranium tailings piles is required for the Uranium Mills Tailings Radiation Control Act and an understanding of the degree of resuspension occurring with particulates from the tailings pile source. In order to study the tailings source and resuspension of material, trace element and radiochemical compositions must be studied as a function of their physical particle diameter. This can only be done in a long, time-consuming, very extensive experiment. The data base provided in this study used the Nuclear Regulatory Commission (NRC) network at the Homestake United Nuclear mill at Grants, New Mexico. This large sampling network was automated such that it collected material over several months time periods using automatic controllers which sampled the air as a function of wind direction and wind speed.[1] The air samplers were turned on only when the wind of a given velocity was blowing from the tailings pile toward the samplers. Only through an extensive interpretation of the radiochemical and trace element data can the amount of material being blown directly from the pile and that being resuspended be determined.

EXPERIMENTAL PROTOCOL

The collection of airborne particulates downwind from a uranium tailings pile was accomplished by an automated sampling system designed to only sample air which has blown over the tailings area and which had an appropriate velocity to resuspend that tailings material in significant proportions and transport it to the sampling devices.

During mid-May, 1979, Battelle-Northwest installed high volume Sierra cascade impactor sampling equipment downwind of a tailings pile in the Grants, New Mexico area. The power to the various samplers was controlled as a function of wind speed. The samplers were turned on at a minimum wind speed of 1 m/sec and off at a maximum wind speed of 15 m/sec. The samplers were installed with cyclone preseparators and wind vanes. In this fashion, the sampler was always looking at the pile and the particle preseparator removed large particulate material transported under high wind speed conditions. The samplers were placed at two stations downwind of the tailings pile as illustrated in Figure 1, at 1045 meters on a 10.5° line (R2) and 4280 meters on a 35° line (R4). A 15° operational window was used at the 4000 meter site aiming at the tailings pile, while a 60° window was used at the close-in site, also aimed at the tailings pile. The sampling parameters are listed in Table 1.

DISCUSSION

The concentrations of trace elements which were measured by X-ray fluorescence and neutron activation analysis in the particle size separations are tabulated in Tables 2 and 3. This tabulation contains a tremendous amount of analytical data, some of which is useful in identifying the source of the airborne particulate material. Prior to passage through the particle size separator, the air moved through a cyclone separator where the larger dust particles were removed. The first sections of Tables 2 and 3 present an analysis of these larger fractions. From the uranium concentration, it is evident that a large fraction of this airborne material was from the tailings pile. For example, at the R2 location, samples 1 through 4 all showed concentrations ranging from 40 to 128 ppm of uranium. This can be compared to uranium concentration in the tailings pile of about 200 ppm. At the R2 sampling site, which is about 4000 meters downwind, the uranium concentrations during the four sampling periods ranged from 16 to 70 ppm. Therefore, even at this considerable distance, it appears that the airborne particulate material was mainly from the tailings pile. Similar conclusions would be drawn using selenium as an indicator of tailings material. From analysis of the trace element concentration as a function of particle size, it is evident that a large fraction of the trace elements is associated with particle sizes of less than 0.5 microns.

To obtain some information on the radionuclide transport, we combined all of the filters of each particle size range for the four sets of measurements. These composite samples were then counted on a large intrinsic germanium diode to permit analysis of ^{210}Pb, ^{226}Ra, ^{230}Th, and ^{238}U (see

Table 4). These measurements indicate that a majority of each of these radionuclides is present on the <0.5 micron back-up filter. They also indicate that relative to ^{226}Ra, there is a large excess of ^{210}Pb at both the 1000 and 4000 meter sampling sites. This is presumably due to the decay of radon in the air and the formation of ^{210}Pb. The uranium concentration is approximately one-half of the radium and this is approximately ten-fold higher than the ratio in the tailings pile. From other studies which have been made at this site, we believe that this may simply be due to a mixture of natural soil and tailings material in the aerosol that has been collected at the sampling site.

SUMMARY

From this limited study, it is evident that there is a substantial contribution of tailings material to the natural aerosol at distances of 1000 to 4000 meters downwind from this dry tailings pile. This is clear both from the radionuclide composition and from key trace elements which are characteristically high in the tailings material. Also, a major fraction of resuspended tailings material is associated with particles of <0.5 microns.

RECOMMENDATIONS

Since the data obtained from this task were taken under a wide integrating range of wind speeds, we recommend that further measurements be made as a function of wind speed to determine what the actual suspension of tailings material produces in the way of aerosol concentrations downwind from tailings piles of this type. We also recommend that the data developed in this report on trace elements be further analyzed and compared with the trace element composition of tailings material and of ambient soil so that with this information a more quantitative estimate of resuspension of both radioactive and trace elements can be obtained.

Figure 1. Site Locations for Airborne Particulate Collection

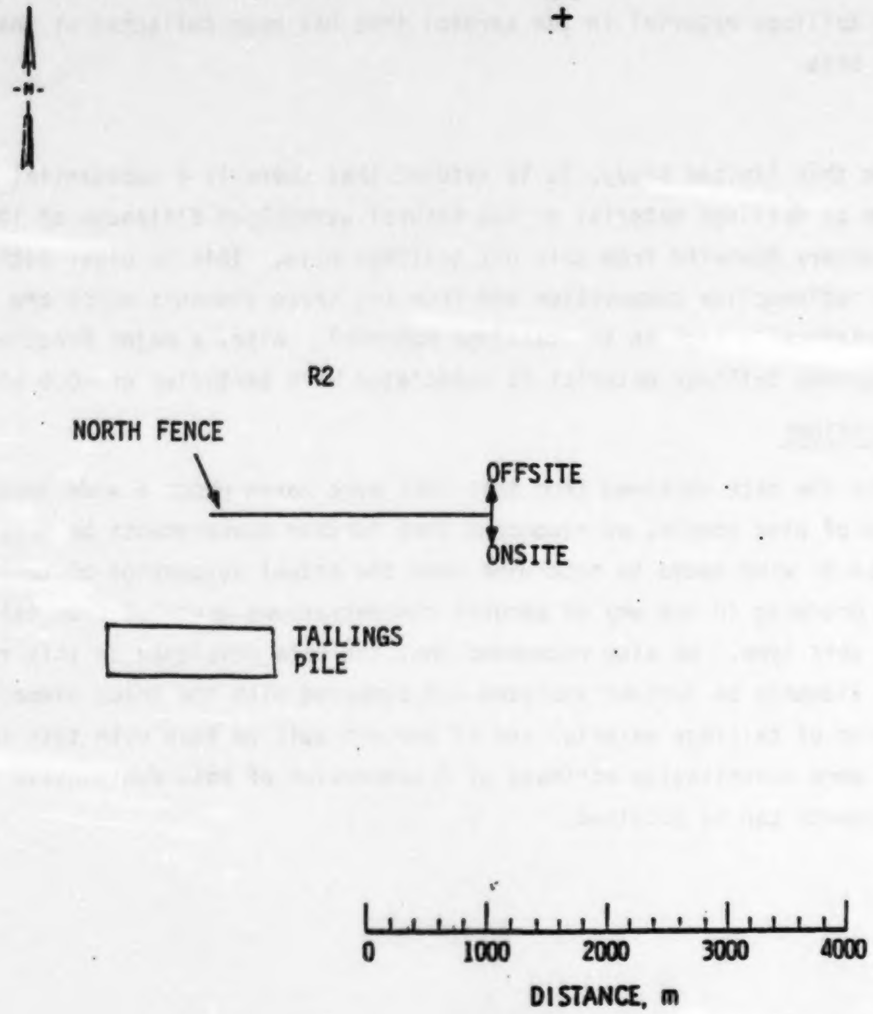

R4
N
R2
NORTH FENCE
OFFSITE
ONSITE
TAILINGS PILE
0
1000
2000
3000
4000
DISTANCE, m

Table 1. Sierra Impactor Sampling Parameters - Homestake Partners, Grants, N.M.

Sample Site	Sierra No.	Location	Sampling Period	Running Time Minutes	Total Volume m^3	Width of Wind Direction Sampling Window	Wind Speed Sampled
Roundy 2 (R2)	#1	870 Meters North of Tailings Pile	5/5/79 1600 to 7/9/79 1130	10851.9	12292	60°	All
	#2			8446.7	9567	60°	All
	#3			10940.4	12392	60°	All
	#4			8934.9	10120	60°	All
				Total	44371		
Roundy 4 (R4)	#1	4220 Meters Northeast of Tailings Pile	5/15/79 1615 to 7/9/79 1030	7118.9	8063	15°	All
	#2			7309.8	8280	15°	All
	#3			2815.8	3189	15°	All
	#4			7310.9	8281	15°	All
				Total	27813		

Table 2. Trace Element Analysis of XRF of Sierra Cyclone Separated Dust Downwind of Homestake Partners Tailings Pile, Grants, New Mexico, 5/15/79 to 7/9/79†

Element	R2 #1	R2 #2	R2 #3	R2 #4
Si (%)	19.9 ± 1.1	19.3 ± 1.1	21.6 ± 1.2	14.4 ± .8
P (%)	.420 ± .148	.529 ± .159	<.25	.319 ± .124
S (%)	.900 ± .071	.896 ± .075	.465 ± .051	.682 ± .060
Cl (%)	.079 ± .021	.126 ± .023	.040 ± .016	.090 ± .019
K (%)	1.27 ± .07	1.36 ± .07	.944 ± .050	.999 ± .052
Ca (%)	7.72 ± .39	9.49 ± .48	4.33 ± .22	5.82 ± .29
Ti (%)	.184 ± .010	.223 ± .012	.105 ± .006	.134 ± .007
V (ppm)	118 ± 16	177 ± 20	58.7 ± 10.7	87.1 ± 12.6
Cr (ppm)	263 ± 16	147 ± 11	112 ± 8	144 ± 10
Mn (ppm)	365 ± 20	407 ± 22	206 ± 12	282 ± 16
Fe (%)	1.38 ± .07	1.28 ± .06	.675 ± .03	1.38 ± .07
Ni (ppm)	72.6 ± 4.5	38.6 ± 2.9	28.7 ± 2.4	46.6 ± 3.2
Cu (ppm)	154 ± 8	61.3 ± 3.4	29.6 ± 1.9	94.2 ± 5.0
Zn (ppm)	254 ± 13	202 ± 10	159 ± 8	291 ± 15
Ga (ppm)	4.55 ± .71	5.44 ± .64	3.38 ± .58	1.90 ± .60
Hg (ppm)	<3.0	2.7	<2.6	<2.6
Se (ppm)	75.0 ± 3.9	88.0 ± 4.5	48.2 ± 2.6	66.1 ± 3.4
Pb (ppm)	52.3 ± 3.4	45.9 ± 3.0	32.1 ± 2.6	40.8 ± 3.1
As (ppm)	14.2 ± 1.1	15.6 ± 1.1	11.1 ± 1.0	11.4 ± 1.0
Br (ppm)	8.66 ± .62	7.28 ± .53	3.87 ± .47	11.4 ± .7
Rb (ppm)	46.8 ± 2.4	48.6 ± 2.5	46.4 ± 2.5	39.4 ± 2.1
U (ppm)	127 ± 9	128 ± 10	40.8 ± 3.9	91.0 ± 6.9
Sr (ppm)	178 ± 12	196 ± 14	118 ± 8	140 ± 10
Y (ppm)	16.6 ± 1.4	18.2 ± 1.4	10.7 ± 1.0	13.3 ± 1.1
Zr (ppm)	168 ± 12	213 ± 15	265 ± 19	210 ± 15
Nb (ppm)	8.38 ± .91	7.76 ± .81	5.67 ± .78	7.34 ± .79
Mo (ppm)	42.8 ± 3.2	59.2 ± 4.24	17.2 ± 1.57	52.9 ± 3.8

†R2 #1, 2, 3, 4 are the samples collected by Sierra sampler 1, 2, 3, 4 at location R2.
R4 #1, 2, 3, 4 are the samples collected by Sierra sampler 1, 2, 3, 4 at location R4.

Table 2. (contd)

Element	R4 #1	R4 #2	R4 #3	R4 #4
Si (%)	19.3 ± 1.0	16.6 ± .9	22.2 ± .32	5.29 ± .32
P (%)	.331 ± .115	.246 ± .061	.190 ± .058	.388 ± .058
S (%)	.547 ± .052	.192 ± .024	.223 ± .028	.319 ± .028
Cl (%)	.134 ± .020	.037 ± .009	.067 ± .009	.053 ± .009
K (%)	1.29 ± .07	.797 ± .042	1.05 ± .028	.544 ± .028
Ca (%)	3.25 ± .16	.706 ± .037	1.00 ± .049	.967 ± .049
Ti (%)	.168 ± .009	.083 ± .005	.092 ± .004	.065 ± .004
V (ppm)	79.5 ± 12.0	31.2 ± 10.8	34.8 ± 5.7	29.8 ± 5.7
Cr (ppm)	427 ± 23	19.3 ± 5.7	12.1 ± 4.8	64.8 ± 4.8
Mn (ppm)	286 ± 16	128 ± 9	117 ± 5.8	94.0 ± 5.8
Fe (%)	1.16 ± .058	.722 ± .036	.632 ± .024	.470 ± .024
Ni (ppm)	90.7 ± 5.2	10.3 ± 2.6	5.81 ± 1.7	20.4 ± 1.7
Cu (ppm)	74.6 ± 4.1	33.4 ± 2.7	22.4 ± 1.9	31.0 ± 1.9
Zn (ppm)	429 ± 22	274 ± 15	56.9 ± 8	146 ± 8
Ga (ppm)	5.36 ± .75	3.68 ± 1.11	4.63 ± .47	2.85 ± .47
Hg (ppm)	3.0	5.2	2.4	2.2
Se (ppm)	25.9 ± 1.5	12.9 ± 1.2	18.3 ± 1.0	17.9 ± 1.0
Pb (ppm)	117 ± 6	26.9 ± 3.4	27.9 ± 2.0	26.6 ± 2.0
As (ppm)	12.1 ± 1.2	5.61 ± 1.21	9.00 ± .67	5.85 ± .67
Br (ppm)	26.5 ± 1.5	7.5 ± .9	21.4 ± .6	8.6 ± .6
Rb (ppm)	53.0 ± 2.8	40.9 ± 2.5	53.8 ± 1.5	27.0 ± 1.5
U (ppm)	70.4 ± 5.8	16.3 ± 4.8	18.5 ± 2.7	24.2 ± 2.7
Sr (ppm)	129 ± 9.1	54.7 ± 4.1	76.6 ± 3.8	52.8 ± 3.8
Y (ppm)	15.5 ± 1.3	8.4 ± 1.3	11.7 ± .8	7.3 ± .8
Zr (ppm)	187 ± 13	127 ± 9	181 ± 5.1	72.2 ± 5.1
Nb (ppm)	9.38 ± .94	4.64 ± 1.29	8.84 ± .74	6.00 ± .74
Mo (ppm)	25.5 ± 2.0	7.86 ± 1.84	15.9 ± 1.08	10.8 ± 1.08

Table 3. Trace Element Analysis by Neutron Activation on Sierra Impactor Samples of Aerosols Downwind of Homestake Partners Tailings Pile, Grants, New Mexico, 5/15/79 to 7/9/79 by XRF

	R2 #1 ng/m³					
ECD†	>7.2µ	3.0-7.2µ	1.5-3.0µ	0.95-1.5µ	0.49-0.95µ	<0.49µ
Element						
Al	<80	<90	<90	<95	<80	<400
Si	280 ± 30	370 ± 30	390 ± 30	380 ± 30	270 ± 30	2900 ± 140
S	22.0 ± 6.6	38.9 ± 6.6	46.6 ± 7.0	49.3 ± 7.5	88.4 ± 7.9	150 ± 30
Cl	<5.7	10.4 ± 2.8	9.14 ± 3.00	<6.2	<6.2	21.8 ± 10.8
K	19.2 ± 3.1	31.4 ± 3.4	31.7 ± 3.5	28.9 ± 3.3	29.0 ± 3.2	191 ± 10
Ca	152 ± 2.7	209 ± 3.1	177 ± 2.9	160 ± 1.8	140 ± 2.5	1150 ± 10
Ti	4.78 ± 0.50	6.99 ± 0.57	7.13 ± 0.54	5.63 ± 0.54	6.21 ± 0.49	35.4 ± 1.6
V	0.49 ± 0.14	0.88 ± 0.35	0.92 ± 0.17	0.71 ± 0.33	0.59 ± 0.15	4.5 ± 1.0
Cr	0.66 ± 0.25	0.68 ± 0.11	0.72 ± 0.11	0.63 ± 0.25	0.65 ± .10	3.4 ± 0.76
Th	<0.40	<0.42	<0.40	<0.37	<0.37	<1.19
Mn	0.920 ± 0.089	1.55 ± 0.24	1.60 ± 0.23	1.33 ± 0.23	1.28 ± 0.21	6.9 ± 0.65
Fe	41.0 ± 0.68	70.9 ± 0.87	73.0 ± 0.87	66.6 ± 0.85	74.1 ± 0.79	359.1 ± 2.0
Co	<0.28	<0.33	<0.34	<0.34	0.38 ± 0.15	<1.19
Ni	0.29 ± 0.10	0.38 ± 0.12	0.32 ± 0.043	0.370 ± 0.047	0.352 ± 0.104	1.39 ± 0.36
Cu	0.40 ± 0.043	0.82 ± 0.12	0.83 ± 0.13	1.09 ± 0.13	1.55 ± 0.13	4.37 ± 0.33
Zn	0.387 ± 0.040	0.799 ± 0.108	1.04 ± 0.11	1.46 ± 0.11	2.69 ± 0.14	7.10 ± 0.35
Ga	<.063	<0.064	<0.064	<0.070	<0.070	<0.21
Hg	<0.23	<0.21	<0.21	<0.23	<0.22	<1.92
Se	0.422 ± 0.094	0.742 ±	0.765 ± 0.041	0.794 ± 0.085	1.51 ± 0.089	3.27 ± 0.18
Pb	0.293 ± 0.120	0.738 ± 0.251	0.736 ± 0.254	1.03 ± 0.26	1.51 ± 0.26	11.5 ± 0.79
As	<0.080	0.134 ± 0.041	0.191 ± 0.044	0.191 ± 0.047	0.473 ± 0.26	1.59 ± .42
Br	0.104 ± 0.033	0.223 ± 0.086	0.369 ± 0.034	0.340 ± 0.079	0.708 ± 0.082	1.35 ± 0.23
Rb	<0.20	<0.19	<0.20	<0.21	<0.20	.79 ± 0.27
U	0.622 ± 0.239	0.770 ± 0.246	0.816 ± 0.255	1.08 ± 0.25	1.52 ± 0.24	5.05 ± 0.69
Sr	0.476 ± .083	0.719 ± 0.085	0.701 ± 0.083	0.425 ± 0.084	0.554 ± 0.080	3.21 ± 0.23
Y	<0.16	0.16 ± .075	<0.15	<0.17	<0.15	<.46
Zr	<0.20	0.32 ± 0.095	0.20 ± 0.093	<0.19	0.27 ± 0.090	1.95 ± 0.28
Nb	<0.21	<0.19 ±	<0.19	<0.20	<0.18	<0.57
Mo	<0.23	0.29 ± 0.14	<0.24	0.44 ± 0.11	<0.21	<0.62

†Effective cut-off diameter.

Table 3. (contd)

ECD†	>7.2μ	3.0-7.2μ	1.5-3.0μ	0.95-1.5μ	0.49-0.95μ	0.49μ
			R2 #2 ng/m³			
Element						
Al	<100	<130	<94	< 103	<94	925 ± 212
Si	464.9 ± 36.8	567.6 ± 41.2	370 ± 330	393 ± 36.2	309 ± 33.9	2753 ± 151
S	36.8 ± 9.0	54.3 ± 9.2	55.6 ± 8.3	71.5 ± 8.8	121 ± 10.2	577 ± 35.4
Cl	27.4 ± 8.0	27.4 ± 7.2	24.3 ± 6.1	<7.5	<8.12	<27.1
K	25.6 ± 3.8	40.3 ± 4.1	35.9 ± 4.0	36.0 ± 4.2	32.5 ± 3.9	199 ± 12.0
Ca	184 ± 3.2	254 ± 3.8	186 ± 3.3	188 ± 3.4	143 ± 2.8	1056 ± 11
Ti	4.75 ± 0.6	6.79 ± 0.70	7.06 ± 0.61	8.55 ± 0.68	5.82 ± 0.59	32.6 ± 2.0
V	.34 ± 0.20	.62 ± 0.21	1.32 ± 0.41	0.71 ± 0.21	0.64 ± 0.18	4.1 ± 1.2
Cr	0.53 ± 0.30	.48 ± 0.12	0.36 ± 0.12	0.39 ± 0.12	0.39 ± 0.11	1.2 ± 0.36
Th	<0.49	<0.47	<0.47	<0.49	<0.46	<1.5
Mn	.874 ± 0.25	1.53 ± 0.28	1.38 ± 0.25	1.32 ± 0.280	1.02 ± 0.263	6.60 ± 0.749
Fe	44.2 ± 0.80	74.5 ± 0.99	70.9 ± 0.97	77.5 ± 1.02	62.9 ± 0.878	330 ± 3.12
Co	<0.32	<0.39	<0.38	<0.42	<0.36	<1.3
Ni	<0.92	0.21 ± 0.05	0.15 ± 0.04	0.22 ± 0.04	0.22 ± 0.05	0.845 ± 0.127
Cu	0.92 ± 0.15	1.50 ± 0.72	2.23 ± 0.17	3.45 ± 0.19	4.35 ± 0.21	11.5 ± 0.525
Zn	.63 ± 0.13	0.74 ± 0.12	0.999 ± 0.13	2.14 ± 0.16	3.73 ± 0.19	11.7 ± 0.489
Ga	< .80	<0.80	<0.08	<0.09	<0.09	<0.267
Hg	<0.28	<0.27	<0.27	<0.28	<0.27	<0.727
Se	.53 ± 0.01	0.923 ± 0.102	0.841 ± 0.103	1.04 ± 0.112	1.77 ± 0.117	7.26 ± 0.335
Pb	.446 ± 0.151	0.694 ± 0.156	0.940 ± 0.281	1.20 ± 0.339	2.40 ± 0.321	13.8 ± 1.02
As	< .98	0.141 ± 0.054	0.154 ± 0.054	0.333 ± 0.167	0.640 ± 0.167	1.82 ± 0.531
Br	0.144 ± 0.041	0.241 ± 0.042	0.396 ± 0.094	0.567 ± 0.104	1.02 ± 0.101	4.95 ± 0.327
Rb	< .22	<0.25	<0.255	<0.275	<0.237	<0.738
U	.676 ± 0.200	1.07 ± 0.31	1.46 ± 0.307	2.04 ± 0.329	2.09 ± 0.293	5.19 ± 0.885
Sr	0.323 ± 0.104	0.726 ± 0.116	0.645 ± 0.101	0.775 ± 0.111	0.552 ± 0.096	2.99 ± 0.279
Y	<0.19	<0.20	<0.18	<0.21	<0.18	<0.52
Zr	<0.25	0.41 ± 0.12	0.39 ± 0.12	0.42 ± 0.12	0.28 ± 0.11	1.6 ± 0.33
Nb	<0.26	<0.25	<0.25	<0.25	<0.24	<0.68
Mo	<0.29	0.38 ± 0.14	0.29 ± 0.14	0.38 ± 0.14	0.38 ± 0.13	2.3 ± 0.38

†Effective cut-off diameter.

Figure 3. (contd)

R2 # 3 ng/m^3

ECD†	>7.72μ	3.0-7.2μ	1.5-3.0μ	0.94-1.5μ	0.49-0.95μ	<0.49μ
Element						
Al	<70	<85	<76	<87	106 ± 37.0	1115 ± 235
Si	317 ± 26	472 ± 32	348 ± 28	415 ± 32	194 ± 25	4571 ± 173
S	22.9 ± 6.2	42.4 ± 6.7	34.0 ± 6.7	52.2 ± 7.5	86.9 ± 7.8	726 ± 34.0
Cl	6.45 ± 2.7	8.1 ± 2.9	6.5 ± 2.9	7.0 ± 3.2	<6.3	<25
K	20.2 ± 2.9	35.3 ± 3.2	27.8 ± 3.1	32.2 ± 3.5	20.2 ± 3.03	266 ± 10.9
Ca	157 ± 2.7	224 ± 3.2	154 ± 2.7	174 ± 2.8	93.7 ± 2.0	1672 ± 12.0
Ti	4.89 ± 0.48	7.20 ± 0.56	5.05 ± 0.53	7.4 ± 0.57	4.45 ± 0.47	44.8 ± 1.89
V	0.38 ± 0.15	0.94 ± 0.32	0.47 ± 0.15	0.97 ± 0.18	0.530 ± 0.14	4.96 ± 1.12
Cr	0.92 ± 0.24	0.66 ± 0.11	0.37 ± 0.09	0.50 ± 0.25	0.43 ± 0.21	3.38 ± 0.772
Th	<0.33	<0.36	<0.37	<0.41	<0.40	<1.2
Mn	0.914 ± 0.198	1.49 ± 0.216	1.31 ± 0.20	1.28 ± 0.228	1.03 ± 0.1-1	9.84 ± 0.732
Fe	35.8 ± 0.629	64.5 ± 0.817	53.6 ± 0.754	65.0 ± 0.824	47.7 ± 0.677	440 ± 3.15
Co	<0.25	<0.34	<0.31	<0.33	<0.28	<1.3
Ni	0.369 ± 0.114	0.319 ± 0.04	0.165 ± 0.032	0.229 ± 0.036	0.554 ± 0.119	1.39 ± 0.380
Cu	0.436 ± 0.09	0.876 ± 0.116	1.26 ± 0.130	2.10 ± 0.143	2.28 ± 0.143	4.50 ± 0.430
Zn	0.403 ± 0.09	0.523 ± 0.098	0.527 ± 0.103	1.34 ± 0.130	2.70 ± 0.150	11.0 ± 0.420
Ga	<0.58	<0.06	<0.07	<0.07	<0.07	<0.22
Hg	<0.20	<0.20	<0.20	<0.06	<0.20	<0.60
Se	0.462 ± 0.072	0.756 ± 0.082	0.672 ± 0.084	0.526 ± 0.094	1.25 ± 0.093	8.35 ± 0.292
Pb	<0.224	0.621 ± 0.116	0.446 ± 0.246	1.03 ± 0.257	2.01 ± 0.267	13.5 ± 0.836
As	0.159 ± 0.105	0.121 ± 0.041	0.213 ± 0.043	0.328 ± 0.049	0.406 ± 0.052	2.41 ± 0.190
Br	0.118 ± 0.031	0.261 ± 0.081	0.320 ± 0.081	0.426 ± 0.090	0.716 ± 0.088	4.63 ± 0.257
Rb	<0.18	<0.19	0.20 ± 0.10	<0.22	<0.20	0.740± 0.321
U	<0.44	0.876 ± 0.233	1.11 ± 0.242	1.53 ± 0.269	1.46 ± 0.242	7.47 ± 0.769
Sr	0.243 ± 0.079	0.803 ± 0.083	0.490 ± 0.087	0.705 ± 0.090	0.472 ± 0.076	4.40 ± 0.256
Y	<0.15	<0.14	<0.17	<0.15	<0.15	0.70 ± 0.222
Zr	<0.187	0.298 ± 0.09	0.31 ± 0.09	0.25 ± 0.10	0.34 ± 0.09	1.5 ± 0.27
Nb	<0.19	<0.20	<0.20	<0.21	<0.19	<0.56
Mo	<0.21	0.30 ± 0.11	<0.22	0.50 ± 0.11	0.27 ± 0.11	1.9 ± 0.32

†Effective cut-off diameter.

Table 3. (contd)

	R2 #4 ng/m³					
ECD†	>7.2μ	3.0-7.2μ	1.5-3.0μ	0.95-1.5μ	0.49-0.95μ	0.49μ
Element						
Al	160 ± 9	<82	<87	<105	180 ± 50	660 ± 230
Si	340 ± 30	390 ± 30	290 ± 30	390 ± 30	260 ± 30	2930 ± 150
S	26 ± 8	41 ± 8	45 ± 8	68 ± 9	121 ± 10	567 ± 34
Cl	<7.0	<6.9	<8.1	8.6 ± 3.5	<7.9	<25.8
K	16.8 ± 1.1	220 ± 1.2	26.9 ± 1.2	31.8 ± 1.2	27.9 ± 1.2	199 ± 5
Ca	152 ± 2	183 ± 2	161 ± 2	163 ± 2	131 ± 2	1289 ± 8
Ti	6.11 ± .32	6.57 ± .33	6.70 ± .35	6.17 ± .33	5.08 ± .30	33.9 ± 1.1
V	.44 ± .17	.74 ± .18	.52 ± .18	.52 ± .18	.65 ± .17	3.46 ± .64
Cr	.87 ± .13	.57 ± .12	.47 ± .12	.68 ± .12	.45 ± .11	3.78 ± .41
Th	<.49	<.49	<.50	<.47	<.45	4.64 ±
Mn	1.04 ± .10	1.24 ± .11	1.29 ± .12	1.44 ± .12	1.34 ± .10	7.61 ± .40
Fe	45.4 ± .4	57.5 ± .5	62.6 ± .5	73.5 ± 0.5	65.1 ± 0.5	403 ± 2
Co	<0.31	<0.35	<0.37	<0.38	<0.35	<1.37
Ni	0.65 ± 0.06	0.72 ± 0.06	0.75 ± 0.06	1.11 ± 0.07	0.86 ± .06	5.02 ± 0.20
Cu	.58 ± .06	.76 ± .07	1.24 ± .07	2.66 ± .09	3.07 ± .09	8.31 ± .23
Zn	.81 ± .05	.58 ± .05	.77 ± .06	1.85 ± .07	3.76 ± .09	11.1 ± .23
Ga	<0.08	<0.07	<0.02	<0.08 ±	<0.08	<0.25
Hg	<0.26	<0.25	<0.25	<0.24 ±	<0.24	<0.66 *
Se	0.41 ± 0.04	0.50 ± 0.04	0.68 ± 0.05	1.08 ± 0.05	1.95 ± 0.06	7.44 ± 0.17
Pb	<0.29	0.47 ± 0.14	0.71 ± 0.15	1.62 ± .15	2.65 ± .16	15.2 ± .5
As	<.099	<.096	<.103	0.19 ± 0.06	0.56 ± 0.07	2.23 ± 0.21
Br	0.13 ± 0.04	0.15 ± 0.04	0.26 ± 0.04	0.46 ± 0.04	1.06 ± 0.05	4.77 ± 0.14
Rb	<.11	<.11	<.11	<.11	<.11	.60 ± .16
U	<.58	.67 ± .21	<.57	1.61 ± .21	1.77 ± .29	<1.3
Sr	<.20	.70 ± .10	<.21	.59 ± .10	.51 ± .10	<.62
Y	<.23	<.19	<.21	<.19	<.19	<.72
Zr	<.25	.37 ± .12	<.23	<.22	<.22	.95 ± .41
Nb	<.28	<.26	<.25	.24 ± .11	<.23	<.90
Mo	<.29	<.27	<.27	.60 ± .13	<.26	1.04 ±

†Effective cut-off diameter.

Figure 3. (contd)

R4 #1 ng/m

ECD†	>7.72μ	3.0-7.2μ	1.5-3.0μ	0.95-1.5μ	0.49-0.95μ	<0.49μ
Element						
Al	270 ± 80	<120	<110	<102	<90	1080 ± 200
Si	330 ± 40	340 ± 40	270 ± 30	260 ± 30	190 ± 30	950 ± 100
S	30 ± 12	41 ± 11	37 ± 11	43 ± 11	110 ± 10	380 ± 50
Cl	18.6 ± 5.1	23.8 ± 4.7	14.7 ± 4.8	12.5 ± 4.9	<9.7	<42
K	18.0 ± 4.8	22.3 ± 4.5	25.3 ± 4.5	20.9 ± 4.4	16.8 ± 4.1	65.2 ± 13.0
Ca	74.1 ± 2.5	110 ± 3	93.9 ± 2.8	73.0 ± 2.4	47.6 ± 2.0	202 ± 6.2
Ti	4.19 ± 0.71	5.35 ± 0.68	4.41 ± 0.69	3.60 ± 0.69	4.00 ± 0.62	11.6 ± 1.7
V	<0.33	<0.37	0.38 ± 0.19	<0.36	<0.29	<0.93
Cr	0.22 ± .12	<0.22	0.30 ± 0.13	<0.23	0.26 ± 0.10	<0.62
Th	<0.67	<0.61	<0.62	<0.63	<0.65	<2.5
Mn	1.17 ± 0.28	1.28 ± 0.29	1.14 ± 0.30	1.06 ± 0.284	0.839 ± 0.256	3.38 ± 0.71
Fe	30.0 ± 0.73	45.8 ± 0.86	49.3 ± 0.91	43.1 ± 0.85	31.2 ± 0.72	105 ± 2.0
Co	<0.29	<0.34	<0.35	<0.32	<0.27	<0.82
Ni	<0.082	<0.10	0.183 ± .044	<0.078	0.124 ± 0.042	<0.22
Cu	0.863 ± 0.183	1.99 ± 0.20	2.49 ± 0.22	4.22 ± 0.24	5.07 ± 0.24	8.72 ± 0.57
Zn	0.384 ± 0.051	0.460 ± 0.156	0.557 ± 0.154	0.840 ± 0.157	1.19 ± 0.17	3.38 ± 0.46
Ga	<0.098	<0.098	<0.10	<0.10	<0.10	<0.35
Hg	<0.36	<0.32	<0.34	<0.32	<0.31	<0.88
Se	0.169 ± 0.051	0.153 ± 0.047	0.362 ± 0.111	0.308 ± 0.122	0.468 ± 0.048	1.55 ± 0.36
Pb	1.56 ± 0.20	3.01 ± 0.41	3.45 ± 0.42	4.41 ± 0.42	5.97 ± 0.40	70.6 ± 1.7
As	0.175 ± 0.073	0.300 ± 0.079	0.452 ± .084	0.749 ± .089	1.13 ± 0.095	9.66 ± 0.44
Br	0.71 ± 0.14	1.29 ± 0.14	1.23 ± 0.13	1.43 ± 0.14	2.29 ± 0.14	29.5 ± 0.63
Rb	0.31 ± 0.15	<0.28	<0.28	<0.29	0.36 ± 0.14	<0.88
U	<0.76	<0.45	<0.70	0.719 ± 0.243	<0.66	<2.15
Sr	<0.28	1.01 ± 0.12	0.71 ± 0.13	0.86 ± 0.12	0.53 ± 0.11	1.77 ± 0.32
Y	<0.28	<0.24	<0.27	<0.24	<0.24	<0.80
Zr	<0.33	<0.29	<0.30	<0.29	<0.27	<0.78
Nb	<0.35	<0.30	<0.30	<0.30	<0.29	<0.82
Mo	<0.38	<0.33	0.40 ± 0.16	<0.34	<0.31	<0.90

†Effective cut-off diameter.

Table 3. (contd)

	R4 #2 ng/m³					
ECD†	>7.2μ	3.0-7.2μ	1.5-3.0μ	0.95-1.5μ	0.49-095μ	0.49μ
Element						
Al	<100	<120	<97	<110	<89	<400
Si	260 ± 30	350 ± 40	220 ± 30	310 ± 30	120 ± 30	1530 ± 120
S	24 ± 10	44 ± 11	34 ± 10	49. ± 11	75 ± 11	<91
Cl	15.4 ± 4.3	10.9 ± 4.8	14.3 ± 4.2	10.3 ± 4.7	<9.0	<37
K	22.5 ± 4.5	29.0 ± 4.6	21.1 ± 1.2	27.3 ± 4.5	19.1 ± 4.2	94.4 ± 11.6
Ca	91.5 ± 2.8	125 ± 3.0	89.8 ± 2.6	100 ± 2.8	56.8 ± 2.1	266 ± 6.6
Ti	5.29 ± 0.64	5.36 ± 0.70	4.22 ± 0.67	5.46 ± 0.66	3.45 ± 0.58	16.2 ± 1.8
V	<0.38	0.60 ± 0.19	<0.34	<0.38	<0.33	2.60 ± 1.17
Cr	1.56 ± 0.37	2.07 ± 0.40	2.31 ± 0.41	2.98 ± 0.43	2.51 ± 0.35	6.61 ± 1.02
Th	<0.62	<0.66	<0.64	<0.60	<0.68	<2.2
Mn	1.00 ± 0.29	1.33 ± 0.31	1.26 ± 0.30	1.38 ± 0.31	0.902 ± 0.118	3.84 ± 0.81
Fe	42.6 ± 0.84	61.2 ± 1.0	53.2 ± 0.92	63.9 ± 1.0	44.8 ± 0.81	206 ± 2.7
Co	0.74 ± 0.33	<0.39	<0.36	<0.39	<0.31	<1.0
Ni	0.47 ± 0.18	1.00 ± 0.18	1.24 ± 0.18	1.77 ± 0.19	1.40 ± 0.17	3.25 ± 0.48
Cu	1.21 ± 0.19	3.39 ± 0.22	3.91 ± 0.23	6.30 ± 0.27	7.05 ± 0.27	11.2 ± 0.61
Zn	0.63 ± 0.14	0.80 ± 0.15	0.64 ± 0.16	1.14 ± 0.17	1.53 ± 0.16	4.09 ± 0.42
Ga	<0.096	<0.10	<0.099	<0.11	<0.10	<0.33
Hg	<0.33	<0.32	<0.31	<0.31	<0.30	<0.88
Se	0.167 ± 0.048	0.286 ± 0.048	0.298 ± 0.108	0.398 ± 0.049	0.523 ± 0.114	0.887 ± 0.32
Pb	1.81 ± 0.37	2.99 ± 0.39	3.27 ± 0.29	4.61 ± 0.14	5.93 ± 0.42	58.1 ± 1.6
As	0.168 ± 0.070	0.552 ± 0.077	0.385 ± 0.076	0.627 ± 0.089	1.08 ± 0.091	7.20 ± 0.39
Br	1.06 ± 0.13	1.33 ± 0.13	1.20 ± 0.13	1.74 ± 0.14	2.36 ± 0.14	4.30 ± 0.38
Rb	<0.26	<0.28	<0.27	<0.27	<0.25	<0.73
U	<0.68	<0.69	<0.46	0.690 ± 0.338	<0.65	1.35 ± 0.63
Sr	0.31 ± 0.12	0.90 ± 0.12	0.77 ± 0.12	0.76 ± 0.12	<0.65	1.34 ± 0.32
Y	<0.23	<0.24	<0.22	<0.24	<0.22	<0.67
Zr	<0.26	<0.27	0.43 ± 0.13	0.31 ± 0.14	<0.24	<0.72
Nb	<0.28	<0.30	<0.30	<0.29	<0.25	<0.80
Mo	<0.35	<0.33	0.44 ± 0.15	<0.32	<0.31	1.25 ± 0.43

†Effective cut-off diameter.

Table 3. (contd)

			R4 #3 ng/m^3			
ECD†	>7.2µ	3.0-7.2µ	1.5-3.0µ	0.95-1.5µ	0.49-0.95µ	<0.49µ
Element						
Al	<260	260	250	290	280 140	1500 500
Si	470 ± 70	530 ± 80	390 ± 70	500 ± 80	450 ± 70	2000 ± 300
S	<50	76 ± 26	53 ± 24	73 ± 28	230 ± 30	860 ± 120
Cl	21.7 ± 10.6	26.1 ± 11.1	27.1 ± 10.4	23	23	95
K	35.1 ± 9.7	42.8 ± 10.7	34.8 ± 10.2	45.3 ± 10.6	43.7 ± 9.8	207 ± 31
Ca	145 ± 5.6	185 ± 6.4	140 ± 5.9	154 ± 5.7	123 ± 5.0	611 ± 17
Ti	9.97 ± 1.4	11.3 ± 1.5	8.06 ± 1.51	7.33 ± 1.53	6.99 ± 1.38	26.5 ± 4.0
V	<0.84	<0.86	<0.83	<0.87	0.87 ± 0.41	2.6 ± 1.2
Cr	0.59 ± 0.28	1.48 ± 0.72	<0.52	<0.57	<0.54	<1.5
Th	<1.4	<1.4	<1.5	<1.4	<1.5	<5.5
Mn	0.834 ± 0.259	2.20 ± 0.27	1.45 ± 0.26	2.65 ± 0.62	1.48 ± 0.64	6.81 ± 1.84
Fe	56.7 ± 1.6	84.6 ± 1.9	70.2 ± 1.8	80.0 ± 1.8	72.7 ± 1.7	286 ± 5.3
Co	<0.63	<0.73	<0.67	<0.74	<0.67	<2.2
Ni	0.26 ± 0.11	<0.23	<0.20	0.26 ± 0.11	0.31 ± 0.097	<0.65
Cu	2.77 ± 0.44	4.48 ± 0.48	6.03 ± 0.53	10.1 ± 0.56	13.1 ± 0.63	28.5 ± 1.5
Zn	1.04 ± 0.37	1.41 ± 0.34	1.28 ± 0.34	1.69 ± 0.37	2.76 ± 0.37	10.5 ± 1.0
Ga	<0.24	<0.24	<0.24	<0.26	<0.25	<0.88
Hg	<0.83	<0.82	<0.80	<0.84	<0.77	<2.3
Se	<0.23	0.522 ± 0.280	0.465 ± 0.262	0.764 ± 0.123	0.790 ± 0.258	4.03 ± 0.85
Pb	2.35 ± 0.86	4.30 ± 0.94	5.16 ± 0.90	9.13 ± 0.96	10.3 ± 0.92	128 ± 3.8
As	0.349 ± 0.166	1.01 ± 0.17	0.593 ± 0.174	0.948 ± 0.203	1.98 ± 0.21	17.4 ± 0.96
Br	1.31 ± 0.29	2.11 ± 0.30	1.87 ± 0.29	2.79 ± 0.33	3.98 ± 0.31	57.6 ± 1.4
Rb	<0.64	<0.67	<0.61	<0.67	<0.61	<2.0
U	<1.6	<1.7	<1.6	<1.2	<1.1	5.04 ± 2.53
Sr	<0.58	1.04 ± 0.31	0.98 ± 0.28	1.19 ± 0.30	<0.54	3.40 ± 0.82
Y	<0.59	<0.60	<0.59	<0.51	<0.54	<1.7
Zr	<0.71	<0.74	<0.66	<0.72	0.75 ± 0.30	<2.0
Nb	<0.74	<0.76	<0.73	<0.76	<0.69	<2.1
Mo	<0.79	0.89 ± 0.41	<0.80	<0.82	<0.74	<2.2

†Effective cut-off diameter.

Table 3. (contd)

	R4 #4 ng/m^3					
ECD†	>7.2μ	3.0-7.2μ	1.5-3.0μ	0.95-1.5μ	0.49-0.95μ	0.49μ
Element						
Al	<110	<100	<100	<100	<100	710 ± 200
Si	320 ± 30	330 ± 40	260 ± 30	230 ± 30	138	940 ± 100
S	31 ± 10	35 ± 10	34 ± 10	42 ± 11	109 ± 12	401 ± 52
Cl	11.4 ± 4.4	13.6 ± 4.5	11.9 ± 4.5	<9.0	<9.0	<41
K	20.2 ± 4.1	25.8 ± 4.2	21.1 ± 4.3	23.6 ± 4.2	18.1 ± 4.0	76.6 ± 12.8
Ca	83.9 ± 2.6	100 ± 2.9	76.6 ± 2.4	79.1 ± 2.5	42.3 ± 1.9	252 ± 6.8
Ti	4.00 ± 0.62	4.63 ± 0.65	3.43 0.64	4.84 ± 0.64	3.47 0.59	14.9 ± 0.87
V	<0.36	<0.35	<0.33	<0.34	0.29	<0.93
Cr	0.42 ± 0.11	0.32 ± 0.11	<0.22	<0.24	0.44 0.28	1.01 ± 0.32
Th	<0.57	<0.53	<0.62	<0.60	<0.63	<2.4
Mn	0.82 ± 0.11	1.17 ± 0.29	0.88 ± 0.29	0.82 ± 0.29	0.76 ± 0.23	2.54 ± 0.71
Fe	34.0 ± 0.77	45.0 ± 0.86	39.9 ± 0.81	46.0 ± 0.85	30.6 ± 0.69	132 ± 2.2
Co	<0.64	<0.68	<0.62	<0.65	<0.58	<1.7
Ni	0.16 ± 0.046	0.093 ± 0.039	0.099 ± 0.038	0.19 ± 0.050	0.19 ± 0.049	0.88 ± 0.39
Cu	1.19 ± 0.071	1.87 ± 0.19	2.64 ± 0.20	4.30 ± 0.24	4.70 ± 0.12	9.19 ± 0.56
Zn	0.63 ± 0.053	0.58 ± 0.14	0.69 ± 0.15	0.99 ± 0.15	1.53 ± 0.16	3.87 ± 0.45
Ga	<0.093	<0.092	<0.098	<0.10	<0.10	<0.35
Hg	<0.31	<0.32	<0.33	<0.32	<0.30	<0.90
Se	0.162 ± 0.047	0.206 ± 0.046	0.284 ± 0.046	0.403 ± 0.047	0.690 ± 0.111	1.68 ± 0.35
Pb	1.44 ± 0.36	2.40 ± 0.36	3.33 ± 0.38	4.70 ± 0.39	6.50 ± 0.42	73.3 ± 0.89
As	0.226 ± 0.069	0.354 ± 0.074	0.403 ± 0.077	0.763 ± 0.086	0.952 ± 0.093	9.43 ± 0.44
Br	0.79 ± 0.054	1.00 ± 0.12	1.18 ± 0.13	1.67 ± 0.13	2.35 ± 0.066	30.7 ± 0.60
Rb	<0.27	<0.25	<0.26	<0.27	<0.26	<0.87
U	<0.66	<0.63	<0.66	<0.16	0.567 ± 0.220	<2.1
Sr	0.41 ± 0.12	1.03 ± 0.11	0.72 ± 0.12	0.78 ± 0.11	0.50 ± 0.11	1.89 ± 0.31
Y	<0.23	<0.23	<0.22	<0.23	<0.22	<0.74
Zr	<0.29	<0.28	0.41 ± 0.13	<0.27	<0.24	<0.76
Nb	<0.30	<0.29	<0.27	<0.28	<0.28	<0.81
Mo	<0.32	<0.31	<0.33	<0.31	<0.29	<0.87

†Effective cut-off diameter.

Table 4. Radionuclide Concentration in Aerosols Collected by Sierra Impactors as a Function of Particle Size

		PCi/10^3M^3			
Sample Site	Particle Size	^{210}Pb	^{226}Ra	^{230}Th	^{238}U
R-2	>7.2μ	0.51	0.49	<0.30	0.18
R-2	3.0 - 7.2μ	0.70	0.59	<0.41	0.33
R-2	1.5 - 3.0μ	0.76	0/69	<0.30	0.32
R-2	0.95 - 1.5μ	1.10	0.78	<0.46	0.47
R-2	0.49 - 0.95μ	1.80	0.26	<0.31	0.46
R-2	<0.49μ	15.4	4.77	4.48	2.34
R-4	7.2μ	0.25	<0.47	<0.59	<0.17
R-4	3.0 - 7.2μ	0.27	0.39	<0.58	<0.23
R-4	1.5 - 3.0μ	0.51	0.39	<0.59	<0.21
R-4	0.95 - 1.5μ	0.81	<0.51	<0.70	<0.17
R-4	0.49 - 0.95μ	2.22	<0.48	<0.63	<0.34
R-4	<0.49μ	14.3	0.83	<0.74	0.44

APPENDIX

RADON MEASUREMENT BY CHARCOAL SAMPLING

Radon collection was made using small charcoal canisters containing approximately 75 grams of activated charcoal. The collection system was assembled by mating the charcoal canister with a small lucite cylinder to hold the charcoal aboveground and define the exact area of exhalation. A thin tedlar film served to cover the top surface of the canister, thus allowing external pressure variations to be more closely approximated on the surface being sampled.

At Morton Ranch, these charcoal canisters were exposed for one day. At the mine areas in the Grants, New Mexico region, canisters were exposed for a minimum of four days and a maximum of ten days. Samples from the Wyoming area were analyzed after attainment of radon daughter equilibrium at the Pacific Northwest Laboratory, Richland, Washington, using multidimensional gamma-ray spectrometers. These systems are described in Nuclear Instruments and Methods, Vol. 50, 1967, pages 1 through 10. Briefly, the systems are fabricated from large 11" diameter x 6" thick NaI(Tl) activated crystals which are separated from their phototubes by 4" thick pure NaI lightpipes. Each NaI(Tl) crystal is surrounded by a plastic phosphor or NaI(Tl) anticoincidence annulus. The spectrometer is coupled to a 4096-channel multiparameter analyzer and uses the gamma-ray decay characteristics of each radionuclide for its identification and measurement. The final data analysis is done with a PDP-15 computer program which allows the measurement of radon through its gamma-emitting daughter products. Charcoal canisters from the Grants, New Mexico area were, in general, analyzed at the EPA Montgomery laboratory.

RADIUM, THORIUM, AND POTASSIUM RADIONUCLIDE ANALYSES

A variety of multidimensional gamma-ray spectrometers were used to analyze the particulates in water, air filter particulates, and soils obtained in the Grants, New Mexico and Douglas, Wyoming uranium mining areas. These gamma-ray detection systems utilize pairs of NaI(Tl) activated crystals which are attached to their phototubes by pure NaI lightpipes. Each NaI(Tl) activated crystal is surrounded by a plastic phosphor or NaI(Tl) anticoincidence shield. Each spectrometer is coupled to a 4096-channel multiparameter analyzer and uses the gamma-ray decay characteristics of each radionuclide for its identification and measurement. This is accomplished by viewing the sample with the two NaI(Tl) detectors operating in coincidence and cancelling those events not totally absorbed in the principal detectors by the anticoincidence annulus. Coincidence counts are stored in an energy-energy plane of the memory according to their photon energies, while single gamma rays which interact with either crystal are stored in a normal manner on the X or Y axis. The axis and energy-energy plane backgrounds, backscatter effects, Compton response, and efficiency parameters are stored in a PDP-35 computer memory and used to analyze the collected gamma spectrometer data. In this fashion, ^{228}Th was measured in all samples using the ^{208}Tl gamma rays. Radium-226 was analyzed using the photons from ^{214}Bi and ^{40}K was measured with its single 1.46 MeV photon. Counting was delayed for several weeks after sealing the samples in aluminum cans to permit a near-equilibrium build-up of radon, and hence ^{214}Bi, from which the ^{226}Ra was inferred.

TRACE ELEMENT ANALYSIS IN AQUEOUS SAMPLES

Fifteen trace elements were analyzed in the water samples by two techniques. Plasma emission spectrometry was used for the elements molybdenum, copper, beryllium, aluminum, nickel, cobalt, cadmium, manganese, barium, vanadium, zinc, and iron. Sample pretreatment consisted simply of addition of a small amount of lithium ionization buffer. Samples were run directly against a single standard with double distilled water plus lithium used as the instrument blank. The instrument used was an SMI Echelle spectrometer with a Spectrospan III D.C. argon plasma excitation source. Analysis was carried out in sequential single element mode. A graphite furnace atomic absorption procedure was used for lead, arsenic, and selenium to obtain adequate sensitivity for these elements. Lead samples were run directly as received. Samples for arsenic and selenium were made 0.05% in nickel to minimize losses during pyrolysis. The instrument used was an ILA 257 atomic absorption spectrometer with a Model 555A graphite furnace. Samples were aspirated onto a cylindrical pyrolytic graphite cuvette using an ILA FASTAC autosampler in semi-automatic mode. Standardization was by freshly prepared dilution of stock AA standards. It should be noted that of the trace elements originally requested, no data are reported for antimony or mercury. High sensitivity analysis of antimony is possible by GFAA; however, since no antimony lamp was available, it could not be done within the required time scale. Mercury analysis requires special sampling techniques which were not utilized on these samples. We therefore felt that any mercury data obtained on these samples would not be meaningful and did not attempt to analyze for mercury.

ELEMENTAL ANALYSIS OF SOILS BY X-RAY FLUORESCENCE (XRF)

The granular geological grab samples were homogenized, coned, and quartered to select a representative aliquot of about 4 grams. This aliquot was then reduced to near 100 mesh by alumina mortar and pestle. Samples of approximately 400 mg were then prepared for X-ray fluorescence analysis by forming wafers of 7.9 cm^2 at 3700 kg/cm^2 pressure. These wafers were sequentially fluoresced with three excitation sources to provide a broad range of elemental analyses and maximum sensitivities. The sources used were a zirconium secondary source from a tungsten tube excited at 50 kV and 14 mA; a silver secondary source from a tungsten tube excited at 45 kV and 25 mA; and a ^{241}Am isotopic source. The zirconium excitation lasted 30 minutes, the silver excitation 45 minutes, and the ^{241}Am excitation 60 minutes.

The fluorescence systems employed were KEVEX Model 810 tube-excited system and a radioisotope-excited laboratory system. X-ray spectra were collected with an 80 mm^2 x 5 mm Si(Li) diode and accumulated by computer-based multichannel analyzers (Models 4410 and 4420, Nuclear Data, Inc.). Reduction of the multichannel-analyzer data to elemental concentrations was accomplished by a PDP 11/35 computer using FORTRAN programs SAP and SAP3 (Nielson, 1977).* Analysis of particulate matter in the aqueous samples was accomplished by fluorescing the 0.4 μm filters directly and analyzing the resulting data in terms of the total volume of liquid passed through the filter.

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*Nielson (1977) SAP3: A Computer Program for X-ray Fluorescence Data Reduction, BNW-2193, Pacific Northwest Laboratory, Richland, Washington.

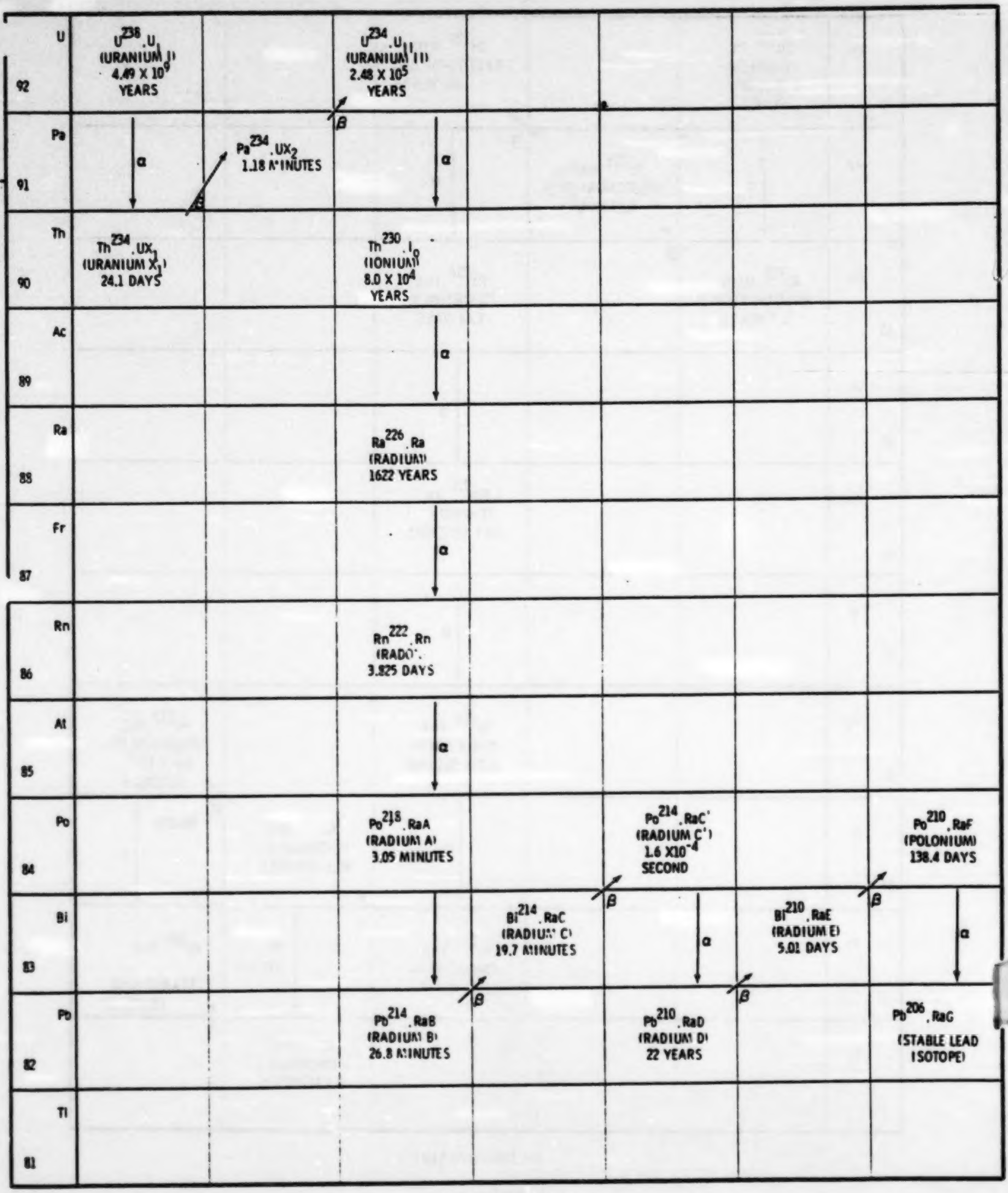
ELEMENTAL ANALYSIS OF SOILS BY INSTRUMENTAL NEUTRON ACTIVATION ANALYSIS (INAA)

Soil samples (0.5-1.0 gm each) were analyzed for 31 major, minor, and trace elements by well developed sequential INAA procedures using a high efficiency Ge(Li) detector (25%, FWHM 1.8 KeV for 1332 KeV γ of ^{60}Co) and a 2048-channel analyzer. The INAA procedure consisted of one short and one long irradiation and two counting intervals in each irradiation. In short irradiations, the samples were individually irradiated in a pneumatic facility at a flux of ~5 x 10^{11} n/cm^2/sec (100 KW) for 2 minutes each, delayed for 10 minutes and counted for 5 minutes each on the Ge(Li) system. The elements titanium, vanadium, magnesium, and aluminum were measured in this counting. After a delay of 2-4 hours, the samples were again counted for 10 minutes each to measure manganese and sodium. The only mjaor interference is from the reaction Al(n,p) Mg which is estimated as 1% Al = 0.28% Mg. This correction is significant and the reported Mg values contain large uncertainties.

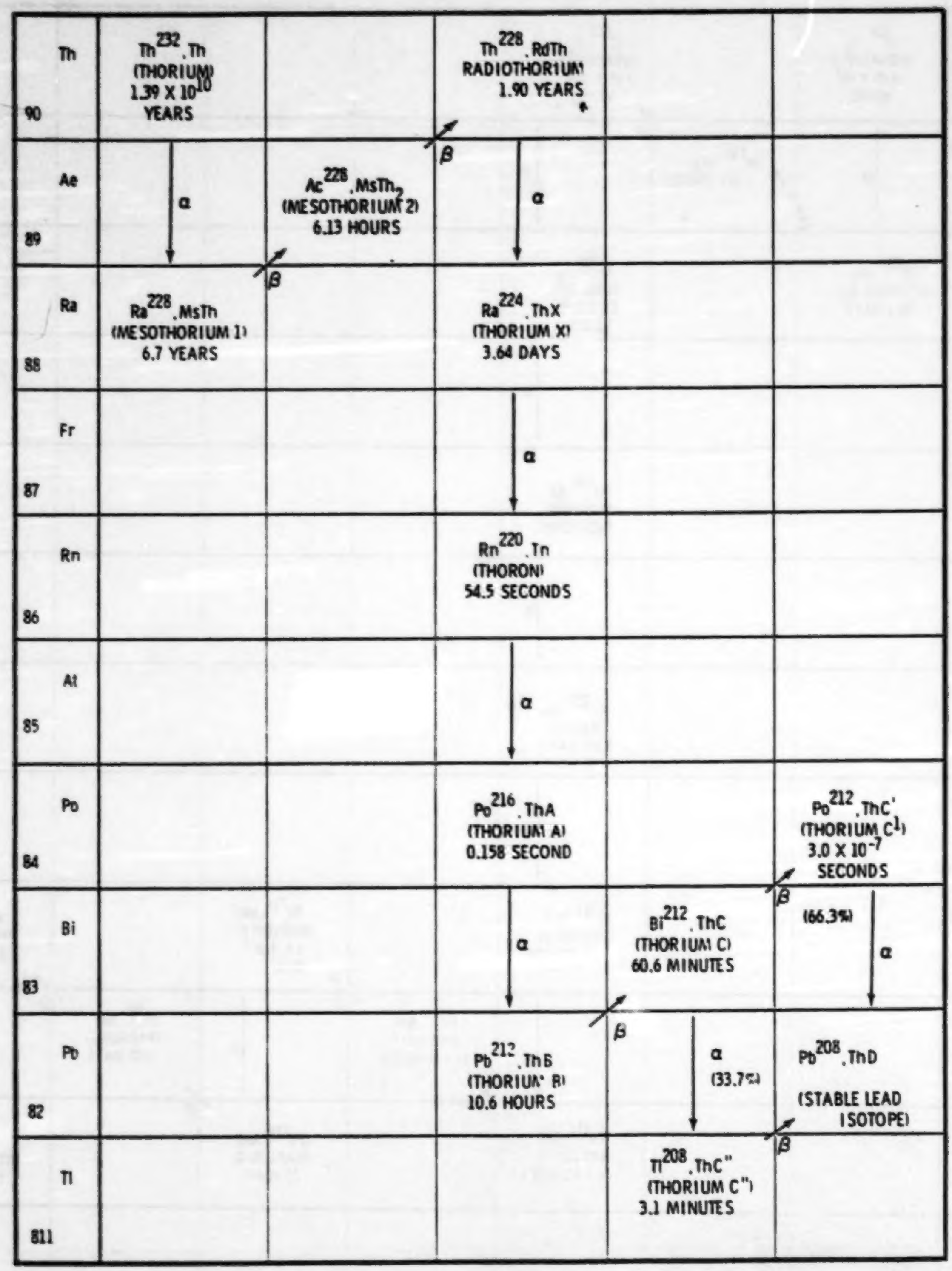
Following the short irradiation, the samples were irradiated at a higher flux of ~5 x 10^{12} n/cm^2/sec (1 MW) for about 4 hours. After a decay of 3-4 days, the samples were counted for 30-60 minutes each on the Ge(Li) system. The elements sodium, potassium, calcium, arsenic, bromine, antimony, barium, lanthanium, neodymium, samarium, ytterbium, lutetium, and uranium were measured in this counting. After another delay of 3-4 weeks, the samples were again counted for 60-200 minutes each to measure scandium, chromium, iron, cobalt, rubidium, zirconium, cesium, cerium, europium, terbium, hafnium, tantalum, and thorium. The only significant interference is from the uranium contributions in the samarium and zirconium determinations, which was corrected. The usual estimated errors based on counting statistics are: ±0.5-5% for sodium, aluminum, scandium, manganese, iron, cobalt, lanthanium, samarium, and ytterbium; ±5-10% for potassium, calcium, titanium, vanadium, chromium, arsenic, bromine, rubidium, antimony, cesium, barium, europium, hafnium, tantalum, thorium, and uranium; ±10-20% for magnesium, zirconium, cerium, neodymium, terbium, and lutetium.

DECAY SCHEMES FOR ^{238}U AND ^{232}Th

The following decay schemes illustrate the inter-relationships of the various radionuclides discussed in this report and also indicate half-lifes of many of the species which were measured.


U
92
Pa
91
Th
90
Ac
89
Ra
88
Fr
87
Rn
86
At
85
Po
84
Bi
83
Pb
82
Tl
81
U^{238}, U_I
(URANIUM I)
4.49 X 10^9
YEARS
α
Pa^{234}, UX_2
1.18 MINUTES
β
Th^{234}, UX_1
(URANIUM X_1)
24.1 DAYS
β
U^{234}, U_{II}
(URANIUM II)
2.48 X 10^5
YEARS
α
Th^{230}, I_0
(IONIUM)
8.0 X 10^4
YEARS
α
Ra^{226}, Ra
(RADIUM)
1622 YEARS
α
Rn^{222}, Rn
(RADON)
3.825 DAYS
α
Po^{218}, RaA
(RADIUM A)
3.05 MINUTES
Pb^{214}, RaB
(RADIUM B)
26.8 MINUTES
β
Bi^{214}, RaC
(RADIUM C)
19.7 MINUTES
β
Po^{214}, RaC'
(RADIUM C')
1.6 X10^{-4}
SECOND
α
Pb^{210}, RaD
(RADIUM D)
22 YEARS
β
Bi^{210}, RaE
(RADIUM E)
5.01 DAYS
β
Po^{210}, RaF
(POLONIUM)
138.4 DAYS
α
Pb^{206}, RaG
(STABLE LEAD
ISOTOPE)

THE URANIUM SERIES


Th
90
Ae
89
Ra
88
Fr
87
Rn
86
At
85
Po
84
Bi
83
Pb
82
Tl
81
Th232, Th (THORIUM) 1.39 X 10^10 YEARS
Th228, RdTh RADIOTHORIUM 1.90 YEARS
Ac228, MsTh2 (MESOTHORIUM 2) 6.13 HOURS
Ra228, MsTh (MESOTHORIUM 1) 6.7 YEARS
Ra224, ThX (THORIUM X) 3.64 DAYS
Rn220, Tn (THORON) 54.5 SECONDS
Po216, ThA (THORIUM A) 0.158 SECOND
Po212, ThC' (THORIUM C') 3.0 X 10^-7 SECONDS
Bi212, ThC (THORIUM C) 60.6 MINUTES
Pb212, ThB (THORIUM B) 10.6 HOURS
Pb208, ThD (STABLE LEAD ISOTOPE)
Tl208, ThC" (THORIUM C") 3.1 MINUTES
α
β
(66.3%)
(33.7%)

THE THORIUM SERIES